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Waterways Experiment Station

Contingency Airfield and Road Construction Using Geosynthetic Fiber Stabilization of Sands

by Steve L. Webster, Rosa L. Santoni

WES

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Prepared for U.S. Air Force Wright Laboratory
and Headquarters, U.S. Army Corps of Engineers

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by Steve L. Webster, Rosa L. Santoni
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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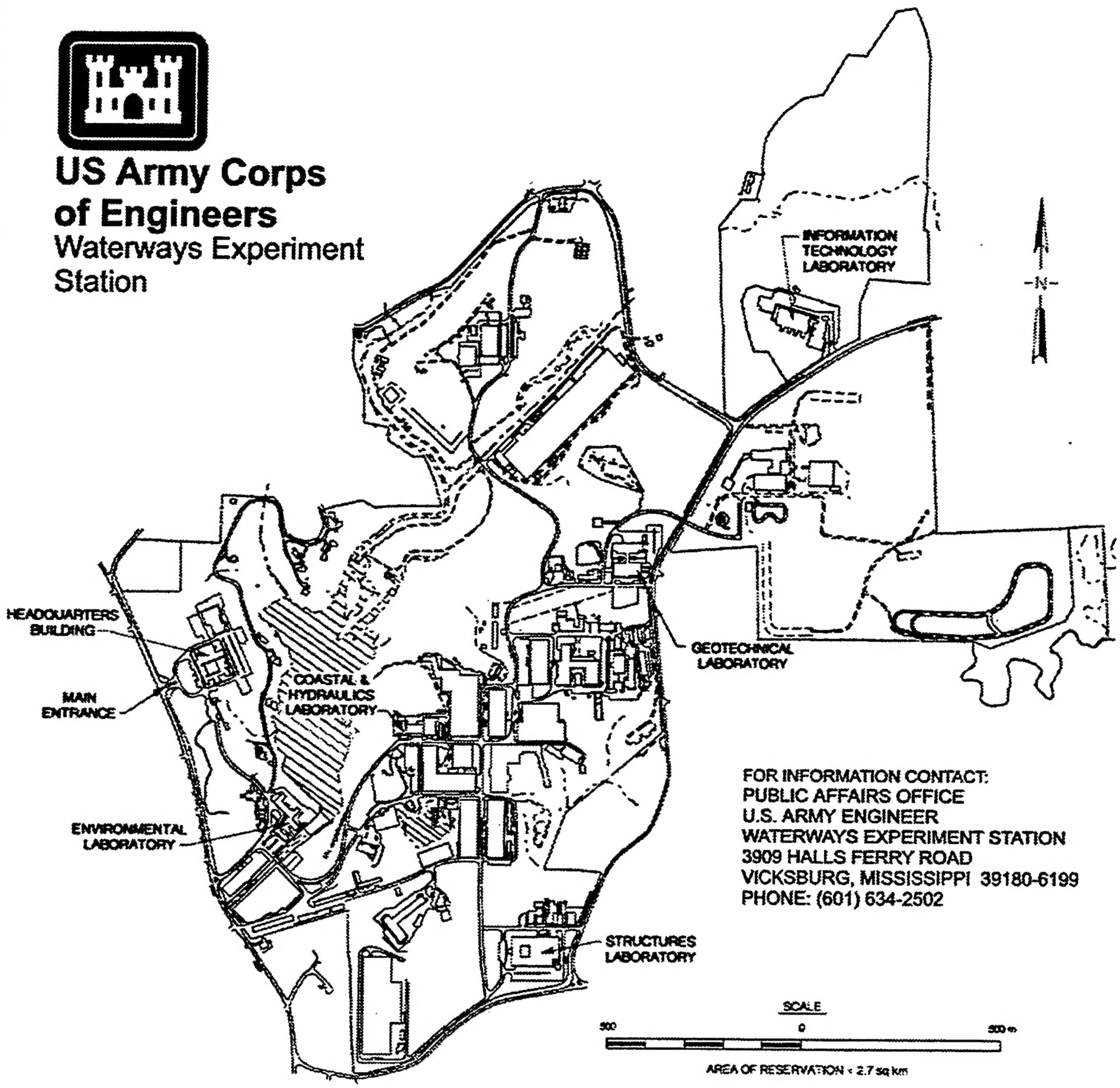

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Contents

Preface

The work described in this report was sponsored by Headquarters, Air Force Civil Engineering Support Agency (HQAFCESA), Tyndall Air Force Base, Florida. The work was conducted under the project "Rapid Airfield Stabilization." Technical monitors were Dr. William Dass and Dr. Jeff W. Rish, ILL, WL/FIVCO, Tyndall Air Force Base. This work was also sponsored by Headquarters, U.S. Army Corps of Engineers, under Work Unit AT40-mm-501, "Advanced Materials for Construction of Contingency Pavement." The Army technical monitor was Mr. Robert A. Harris (ATSE-CTE).

The investigation was conducted by personnel of the Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Dr. W. F. Marcuson III, Director, and under the direct supervision of Mr. Tim W. Vollor, Acting Chief, Airfield and Pavements Division, and Dr. A. J. Bush III, Chief, Technology Application Branch. Staff members actively engaged in the planning and conducting of the investigation were Messrs. S. L. Webster, J. Tingle, T. Williams, and C. Pritchard, LTC R. W. Brown, and Ms. R. L. Santoni. This report was prepared by Mr. Webster and Ms. Santoni.

Director of WES during the conduct of the investigation and preparation of the report was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet (cu ft)	0.02832	cubic meters (m^3)
feet (ft)	0.3048	meters (m)
gallons (gal)	3.785	liters (L)
gallons per square yard (gsy)	4.5273149	liters per square meter (L/m^2)
inches (in.)	0.0254	meters (m)
kips, (1,000 lb)	0.4535924	1,000 kilograms (1,000 kg)
pounds (mass) (lb)	0.4535924	kilograms (kg)
pounds (force) per square inch (psi)	6.894757×10^{-3}	megapascals (MPa)
pounds (mass) per cubic foot (pcf)	0.157	kilonewtons per cubic meter (kN/m^3)
square inches (sq in.)	6.4516×10^{-4}	square meters (m^2)
square yards (sq yd)	0.8361	square meters (m^2)

1 Introduction

Background

Many aircraft sorties are typically required to bring in equipment, supplies, and personnel when the Air Force deploys to a remote location. As the conflict or emergency intensifies, available aircraft parking space at these remote airfields is soon exhausted. To meet mission requirements, the base civil engineer is faced with the task of quickly constructing expanded parking areas, with minimal resources. If the soils around existing aprons are weak or unstable, considerable time can be spent using conventional stabilization techniques for construction. The Corps of Engineers, Waterways Experiment Station (WES), has been working with Wright Laboratory, Tyndall Air Force Base, to develop new soil stabilization techniques that reduce the time required to expand parking areas and aprons.

This report describes a new fiber stabilization technique that improves sandy soils for supporting C-130 and lighter aircraft operations. Aircraft operations in a sand environment produce deep ruts up to 14 in., sometimes resulting in aircraft being immobilized. This new technique uses conventional mixing procedures and equipment to construct runways, taxiways, and aprons. In addition, the new stabilization technique has application for military supply roads and storage areas at remote sites.

A review of the literature indicated that different laboratory tests have been conducted on fiber-reinforced granular material, but the studies were not focused on airfield pavement or road design. Most of the studies showed improvement of soil strength properties through laboratory tests without field validation. Investigations agreed that inclusion of synthetic fibers increase the load carrying capacity (or strength) of sand and improved engineering properties such as shear modulus, liquefaction resistance, and particle interlocking (Maher and Ho 1994, Freitag 1986). The improvement of the engineering properties of the sand was influenced by the fiber content, type, length, and orientation (Gray and Al-Refeai 1986). For fine and medium sand, no appreciable increase in the stiffness of the sand was gained by using fibers longer than 50 mm (2 in.) (Al-Refeai 1991).

Field traffic tests were conducted (Grogan and Johnson 1993) to test stabilization of high plasticity clay and silty sand by inclusion of discrete fibrillated polypropylene fibers for use in pavement subgrades. Truck traffic tests

on the plastic clay material, treated with fiber and 5 percent lime stabilization, provided up to 90 percent more traffic passes to failure than similar test sections without fibers. Truck traffic tests on the sand material, treated with fibers in conjunction with 5 percent portland cement stabilization, provided 60 percent more traffic passes to failure than similar test sections without fibers. Other traffic tests on the sand containing 0.5 percent fibers (1 in. long) showed some enhanced traffic performance, but the results were not considered economically practical.

Ahlrich and Tidwell (1994) conducted laboratory tests to evaluate monofilament and fibrillated fibers for mechanical stabilization of a plastic clay and beach sand. Neither fiber type was very successful in stabilizing the plastic clay. The most successful stabilization of the beach sand was achieved using a 2-in. monofilament fiber at a dosage rate of 0.5 percent by weight.

Purpose

The purposes of this report are to (a) describe initial sand-fiber stabilization experiments conducted, (b) describe laboratory tests conducted to determine optimum fiber content, and (c) present the results of field tests conducted showing the benefits of geosynthetic fibers for rapid airfield and road stabilization.

Scope

This report was limited to laboratory and field tests which involved the use of one type of sand (concrete sand) and one type of fiber (2-in. monofilament polypropylene fiber). Five dosage rates of fiber were evaluated during the laboratory test. In addition, a field mixing test was included to compare laboratory and field performance. During the field test, only one dosage of fiber (1 percent) was evaluated. The operation of a C-130 wheel load (30,000 lb and 100 psi tire pressure) was simulated during field test. Turning and/or braking was not included in the test. Traffic tests were also conducted using a 5-ton military cargo truck (6 by 6, M923) loaded to a gross vehicle weight of 42,000 lb.

2 Initial Sand-Fiber Experiment

Unconfined Compressive Test

Materials

Sand. The sand used for the initial experiment was a local Vicksburg, MS, sand normally used as fine aggregate in concrete. Classification data for this sand are shown in Figure 1. The sand was a pit-run washed sand containing approximately 4 percent gravel sizes and no minus No. 200 U.S. standard sieve size material. It was classified as a poorly graded (SP) sand, American Society for Testing and Materials (ASTM) D 2487 (ASTM 1992). Additional data for the sand are provided in Table 1 (dry unit weights were tested using ASTM D 4253.

Table 1
Sand Properties

Property	Value
Specific gravity	2.65
Laboratory maximum, dry unit weight	117.7 pcf
Laboratory minimum, dry unit weight	98.2 pcf
Coefficient of uniformity	2
Mean diameter	0.5 mm

Fiber. The synthetic fiber used in this investigation was a monofilament polypropylene fiber. It was selected based on a literature review conducted prior to the selection of materials. Research has indicated that the performance of the materials stabilized with the fibers increased with increased length of the fiber up to a length of 2 in. (Al-Refeai 1991). In addition, the 2-in. fiber length allows for easy mixing in the field with a self-propelled rotary mixer. The monofilament fibers were produced by Synthetic Industries, Chattanooga, TN, and were shipped in 20-lb boxes. Table 2 shows the fiber properties.

Table 2
Fiber Properties

Property	Test Method	Typical Values
Polypropylene	ASTM D 4101 (ASTM 1995b) Group 1/Class 1/Grade 2	99.4 percent
Color	---	Natural
Moisture absorption	---	Nil
Fiber length	Measured	2 in.
Specific gravity	ASTM D 792 (ASTM 1991)	0.91
Tensile strength	ASTM D 2256 (ASTM 1995a)	40,000 psi
Young's modulus	ASTM D 2101 (ASTM 1979)	450,000 psi
Denier	Weight in grams of 9,000 m of fiber	50

Specimen preparation and loading

The 2-in.-long monofilament fiber was supplied in yarns. Each yarn contained over 100 individual strands of fiber. Each yarn was pulled by hand to separate the fibers prior to mixing with the sand. Considerable hand work was required in order to separate sufficient quantities of fiber to make sand-fiber test specimens. Measured quantities of fibers were mixed into the sand by hand.

A 12-in. length of 6-in.-diam PVC pipe was used as a mold to make the specimens. The plastic pipe was split lengthwise and taped together. The sand-fiber mix was placed in the cylinder in five layers, and each layer was compacted by five blows using a 10-lb compaction hammer that had an 18-in. free fall distance and a 2-in.-diam striking face. The percentages of fiber used in the samples were 0.2, 0.5, 1, and 2 percent by dry weight of sand. A control sample (sand with no fibers) was included to evaluate the effect of fiber inclusion in the sand. The moisture content of the sand was between 4 and 5 percent. After each specimen was compacted, the tape on the split mold was cut and each half of mold was removed from the specimen. Close examination showed that complete uniform dispersion of the fibers did not occur using hand mixing procedures.

For the initial (quick and dirty) sand-fiber experiment, bricks and steel weights were placed on the top of the specimens to evaluate their load carrying capacity. The bricks weighed approximately 8.5 lb each, and the steel weights were 20 lb each. Various combinations of bricks and steel plates were used to load each sand-fiber column. Figure 2 shows a 201-lb loading on a sand-fiber column stabilized with 1 percent fiber. A piece of plywood was placed over the mold and specimen as shown to help stabilize the rather precarious vertical load applied to the stronger specimens.

Table 3 summarizes the result of the initial sand-fiber tests. The control sample (no fiber) collapsed with an 8.5-lb brick load. The sand-fiber specimens produced higher resistance to deformation than the control sample. The sample containing 2 percent fibers had more initial deformation than the sample with 1 percent fibers. The increased deformation at a lower load caused the test load to tilt and fall.

Table 3
Initial Sand-Fiber Experiment Results

Percent of Fiber	Load (lb)	Deformation (in.)
0.0	8.5	9.5
0.2	33	0.5
0.5	136	7/16
1.0	201	1/8
2.0	102	Tilted

This initial experiment showed that there might be an optimum fiber content beyond which additional fibers degrade the system. Test results coupled with visual observations indicated that as fiber content increased, load-carrying performance increased due to more sand-grain-to-fiber contact. At some point the fiber-content-to-sand-grain ratio becomes too great and a lot of fiber-to-fiber contact exists. The increased fiber content causes a more porous mixture with lower density. Under loading, the sample must undergo more initial deformation before sand-grain-to-fiber contact is achieved.

Field Mixing Experiment

Field mixing experiments were conducted to see if the fibers could be uniformly mixed in sand using standard existing military construction equipment. Figures 3 to 6 show the field mixing procedure using the standard Army self-propelled rotary mixer.

Mixing procedure

The field mixing procedure consisted of spreading the fibers on the sand surface and making repeated passes with the rotary mixer as shown in Figures 3 and 4. Visual observations indicated that four passes were required to separate the yarn into individual fibers and uniformly mix them throughout the sand layer. Figures 5 and 6 show the uniformity of the sand-fiber mix after four passes with the self-propelled rotary mixer.

The field mix of sand and fibers consisted of 3,600 lb of moist concrete sand (SP). The sand had an average moisture content of 6 percent. The amount of fiber used was 80 lb which was 2.4 percent (based on dry weight of the sand) of fiber in the mix. A total of 80 lb of fiber (2.4 percent based on dry weight of the sand) was mixed into the sand. First, 0.2 percent of the fiber was mixed into the sand using four passes of the mixer. The fiber content was then increased to 0.5, 1, and finally 2.4 percent. In all the cases, the fibers in the field mixed material looked very uniformly distributed after four passes of the mixer.

Results

The self-propelled rotary mixer produced a uniform distribution of the sand-fiber mix during the field mixing evaluation. Sand-fiber mixing can be easily accomplished using existing military construction equipment. A 50,000-lb compactor was positioned over two sand-fiber ramps to evaluate the field sample load-carrying capacity of the field mixed material (Figure 7). The sand-fiber ramps supported the heavy weight without significant deformation.

3 Laboratory Tests

Description of Materials

Sand

The sand used in the laboratory tests was concrete sand (SP). Chapter 2 provides a detailed description of the sand properties.

Fibers

The fibers used were 2-in.-long monofilament, polypropylene fiber. Their physical and mechanical properties are described in the initial sand-fiber experiment, Chapter 2.

Preparation and Evaluation

Preparation

In preparing laboratory test specimens, a new method of separating the individual fibers from the yarn was developed. First, a few holes were punched with a paper hole punch near the closed end of a 33-gal plastic bag. Next, a hand full of yarn fibers was placed in the bag. The bag was hand-held-closed around an air nozzle, inverted, and air was blown through the fibers. The air separated the fibers from the yarn effectively and promptly. The separated fibers formed fluffy bundles that resembled cotton candy.

Once the fibers were separated, they were weighed and hand mixed with the sand to as uniform consistency as possible.

Moisture control. The water content of the sand-fiber samples ranged between 5.3 to 7.5 percent. Moisture in the sand was needed to hold the sand-fiber mixture together during mixing. If the sand became too dry, the sand tended to separate from the fibers.

Fiber dosage rates. The percents of fiber used in the samples were 0.2, 0.5, 1.0, 1.5, and 2.0 percent by dry weight of sand. Material from the field

mixed sample containing 2.4 percent of fiber was included in the laboratory tests to evaluate its performance against the laboratory prepared samples. In addition, a control sample (containing no fibers) was included in the laboratory tests.

Specimen mold

A 12-in. length of 6-in.-diam PVC pipe (schedule 40) was used to make the test specimens. The plastic pipe was split lengthwise and taped together to hold the specimen during compaction. After the specimen with mold was positioned in the test machine, the tape was cut and each mold half was carefully removed from the specimen.

Compaction effort

The sand-fiber mix was placed in the cylinder in five layers, and each layer was compacted using five blows of a 10-lb compaction hammer.

Evaluation

Specimens were evaluated by conducting unconfined compression tests. The unconfined strength tests were conducted using an Instron 4208 testing system. The Instron system consists of the test loading instrument and a computer. The test instrument has interchangeable load cells and can be used for tension or compression tests with load-time recording of results. Figure 8 shows the test specimen and mold being positioned in the test instrument. The specimen mold was then removed and a 1-lb seating load was applied. This initial load was required to ensure satisfactory seating of the compression piston, and it was considered as the zero load when determining the load-deformation relation.

The load was applied to each sand-fiber specimen at a constant rate of 0.10 in. per minute. Each specimen was compressed until it reached a total deformation of 1 in. or until it collapsed. Some of the sand-fiber samples were tested to higher deformations to evaluate the sand-fiber performance at high deformations. For example, the samples with 0.5 and 1.0 percent of fibers were compressed until a 6-in. deformation was reached. The field sand-fiber sample (2.4 percent) was also tested for a maximum deformation of 3 in.

Data were collected for the five sand-fiber samples (0.2, 0.5, 1.0, 1.5, and 2.0 percent fibers), the field sand-fiber sample (2.4 percent), and the control sample (no fibers). For each specimen, the applied load and the deformation were recorded at 10 points per second. The data were collected until the sample collapsed or until it reached the preset deformation limit.

Figures 9 and 10 show the control sample (no fibers) before loading and after loading. The control sample collapsed under a load of 9.67 lb.

Significant load improvement results were found for the sand-fiber samples. Figures 11 and 12 show the 1 percent fiber sample before loading and after the application of 750 lb of load with a permanent deformation of 1.5 in. The sample was then subjected to a continuous load increase until 6 in. of deformation occurred under a total load of more than 4,000 lb (Figure 13). Very little sand had fallen from the specimen.

Figure 14 shows plots of the load-deformation data for all test specimens for deflection ranges from 0 to 0.6 in. The plots show that there are optimum fiber contents for maximum loads within this deformation range. For example, from 0 to 0.4 in. of deformation the optimum fiber content of approximately 1 percent produced the maximum loads. Higher fiber contents of 1.5 to 2.4 percent show slow initial strength gain at low deformations with more rapid strength gains at higher deformations. Excess amounts of fiber may interfere with the grain-to-fiber contact that results in a spongy sample that must be compressed before the beneficial grain-to-fiber interaction occurs.

Figure 14 also shows that the field mixed sample (2.4 percent fiber) performed in a similar pattern as the 2.0 percent laboratory prepared specimen. The results showed that the laboratory mixing adequately replicated the field mixing procedure. In both cases, the mix was uniform and the fibers were randomly distributed. It is seen that for this granular soil (SP), a significant improvement in load-carrying capacity was obtained for each sample.

Optimum fiber content. Figures 15 and 16 show plots of load versus fiber content for permanent deformation ranges of 0.10 to 0.25 in. (Figure 15) and 0.25 to 1.0 in. (Figure 16). Figure 15 shows that for low deformations the optimum fiber content is approximately 1 percent (based on dry weight of sand). For larger deformations up to 1.0 in., the optimum fiber content increases to 1.5 percent. Since low deformations are desirable under traffic wheel loads, 1 percent fiber was selected optimum for use in the field experiments.

4 Field Experiments

Test Section Design

Description

Past experience with road and airfield test sections at WES has shown that test section performance was closely related to actual field performance. When new concepts were tried, the test section approach was effective in pointing out potential problems related to construction techniques and permitted adjustments to be made or improvements to be tried. The test section for this study was located under shelter on the WES reservation. It was constructed over the shelters's firm floor, which consisted of compacted lean clay soil.

A plan and profile of the test section is shown in Figures 17 and 18. The test section was designed to test the load-carrying capability of various fiber-reinforced sand test items under C-130 aircraft with wheel loads of 30,000-lb and 100-psi tire pressure. All test items were constructed on an 18-in.-thick sand subgrade. The test section contained two traffic lanes. Each traffic lane contained three test items. Both traffic lanes utilized a distributed type traffic (Figure 19) over a width of five wheel paths (71 in.). After traffic tests were completed on lane 1, the items were reconstructed as shown in the profile in Figure 18. Test items in traffic lane 2 were 8 in. thick, and items in traffic lanes 1 and 1A were 12 in. thick. Sand grid was included in some test items to provide additional stability to the base layer. Road Oyl (a resin modified emulsion bonding agent) was included in some items to provide additional base stability and a wearing surface for the C-130 wheel loads.

Materials

Sand. The sand used for the subgrade and base layer was the same sand used and described earlier in the initial sand fiber experiments and laboratory tests.

Fibers. The monofilament fiber used in the tests was the same 2-in. long polypropylene fibers used and described earlier in the initial sand-fiber experiments and laboratory tests. The fiber used in the test section was

purchased from Synthetic Industries, Chattanooga, TN, for $1.40 per lb and was delivered in 20-lb boxes. Bulk shipping/weight was approximately 18 pcf. A price for bulk quantities was not obtained.

Road Oyl. Road Oyl is a resin modified emulsion that is nonwater soluble and has a high bonding strength. It was developed specifically for use in pavement applications, dust control treatment, and erosion control. It contains selected fractions of natural tree resins combined with a strong bonding agent. It can be field mixed with premoistened materials or diluted with water and sprayed on for surface penetration. It is petroleum-free and can be cold-applied. It is environmentally friendly and available for bulk shipments, 55-gal drums and 275-gal pelletized bulk container packaging. The Road Oyl used in the test section was purchased in 55-gal drums from Road Products Corporation, Knoxville, TN, for $4.23 per gal. The bulk price was approximately $1.79 per gal plus $2.00 per mile per 6,000 gal truck load.

Sand grid. Sand grid (national stock number (NSN) 5680-01-198-7955) is a plastic geocell material designed for confinement of sand or other cohesionless materials to produce a load distributing base layer. Uses of the grid include road and airfield pavements, airfield crater repair, erosion control, field fortifications, and expedient dike repair. The plastic grids are manufactured and shipped in collapsed 4-in.-thick, 110-lb sections. Each expanded grid section is 8 by 20 ft and contains a honeycomb arrangement of cells. Each cell has a surface area of 39 sq in. and a depth of 8 in. Use of sand grid is covered in Army FM 5-430-00-1/AF JPAM 32-8013, Vol I (Headquarters, Departments of the Army and Air Force 1994).

Construction

General

The test section was constructed during the period July-August 1995. All work was accomplished by WES personnel using conventional construction equipment. The test section items were constructed over an 18-in.-thick sand subgrade that was leveled and compacted using a D4 tractor. The sand subgrade was installed on the firm (CBR $>$ 10) CL soil floor in Hangar No. 4 shelter at WES.

Sand grid installation

Sand grid for test items 2, 3, and 5 were installed using a lightweight tubular stretcher frame. The 20-ft-long frame was placed on the subgrade and the sand grid was expanded and attached to vertical prongs at each end of the frame. The frame also contained two rubber straps with hooks along each side rail to secure the grid to the frame. The stretcher frame with attached sand grid was then flipped over as shown in Figure 20 and positioned on the test item as shown in Figure 21. Although the stretcher frame

is not required for sand grid installation, it is useful when only a limited number of workers are available and it ensures correct 20-ft expansion of the grid for proper installation. Sections of grid were joined using hog rings as shown in Figures 21 and 22. Figure 23 shows the test section after grid installation. Two lanes of grid were installed in each item to ensure the joint between grid sections would line up in the middle of the traffic lanes. Sand without fibers was then installed in item 3 and compacted using six passes with a smooth drum vibratory compactor.

Sand-fiber mixing and installation

The sand-fiber mixture used in items 1, 2, 4, and 5 was mixed at a working area adjacent to the test section site. After mixing, the sand-fiber material was installed and compacted in the test section. Figure 24 shows the sand for one of the test items prior to adding the fiber stabilization. The moisture content of the sand was approximately 4 percent. A total of 1 percent fibers (by weight) was mixed into the sand. Figure 25 shows spreading one-half the required fibers on the sand layer. Figure 26 shows a close-up of the fibers on the sand. Each clump of fibers contained several hundred individual fibers each about the diameter of fine human hair. The fibers were mixed into the sand using 4 passes with the self-propelled rotary mixer used by U.S. Army Engineers (Figure 27). The sand-fiber layer was then turned over using a front-end-loader and the remaining fibers were placed and mixed using four passes of the rotary mixer to ensure a uniform sand-fiber mixture for the whole layer. Figure 28 shows the sand-fiber mixture after the final 4 passes with the rotary mixer. Most of the clumps of fibers had disappeared and the hair-like fibers were uniformly mixed throughout the sand.

Figure 29 shows installing the sand-fiber mixture into the sand grid cells as was done in items 2 and 5. Figure 30 shows how the sand-fiber mixture tended to hang-up on the top of the cell walls. In some cases the sand-fiber mixture would bridge over the cells leaving a void in the grid cell. The entire surface of the item was trafficked using the end-loader tires to ensure no voids existed in the grid cells. The sand-fiber filled grids (8-in. depth) were then compacted using six passes with the smooth drum vibratory compactor as shown in Figure 31.

Figure 32 shows item 1 before sand-fiber installation. Metal grade stakes were used to ensure an even 8-in.-deep base layer of sand-fiber. Figure 33 shows the rough looking sand-fiber layer prior to compaction with the vibratory roller. The sand-fiber surface was difficult to smooth using the end-loader bucket. A road grader would have left the surface equally as rough. The sand-fiber mixture tends to act in clumps and resist smoothing efforts with a blade on construction equipment. The sand-fiber mixture was sprayed with water and compacted using six passes with the vibratory roller. After compaction, the surface was smooth and flat. The 8-in.-thick sand-fiber layer was installed in items 1 and 4.

The 4-in.-thick sand-fiber surfacing was then installed over items 1 and 2, sprayed with water, and compacted using six passes with the vibratory roller.

Sand-fiber/Road Oyl

The sand-fiber/Road Oyl material used in various test items was constructed by field mixing the materials at the adjacent work area and then installing and compacting the mixed material in the test section. In addition, a Road Oyl spray application was applied to some of the test items. Table 4 summarizes the sand-fiber/Road Oyl applications. The quantities of Road Oyl listed are for concentrated (undiluted) products as received from the manufacturer. The residual binder content is approximately 48 to 50 percent.

Table 4
Sand-Fiber/Road Oyl Application Summary

Test Item No.	Field Mixed Road Oyl Application Rate, gallons per square yard (gsy) per in. of Depth	Surface Spray Application	
		Road Oyl Quantity, gsy	Water Dilution Ratio Water/Road Oyl
3 & 3A	1	1	no dilution
4	-	1	no dilution
5	-	1	no dilution
6	0.25	1	no dilution
1A	0.6	0.5	2/1
2A	0.3	0.75	2/1

First, the sand and fiber (1 percent by weight) were mixed as described earlier. The required amount of road oyl was then poured onto the sand-fiber layer as shown in Figure 34 and mixed into the sand-fiber layer using two passes of the rotary mixer. The mixture was then turned over using the front end loader and remixed with two additional passes with the rotary mixer. The mixture was then piled as shown in Figure 35 prior to installation in the test section. The fiber and road oyl were very uniformly mixed with the sand.

Installing sand-fiber/Road Oyl. The sand-fiber/Road Oyl base material for item 6 was installed in one layer and compacted with six passes with the smooth drum vibratory compactor to form an 8-in.-thick base layer. The 4 in.-thick sand-fiber/Road Oyl surfacing material for item 3 was installed in one layer after the surface spray application of Road Oyl had been applied. This surfacing layer was compacted with six passes of the smooth drum vibratory compactor. The surfacing for items 1A and 2A were constructed

from the remains of items 1 and 2. The 4-in.-thick surfacing from items 1 and 2 were removed, Road Oyl mixed in, and reinstalled and compacted with six passes of the smooth drum vibratory compactor.

Road Oyl surface spray applications. The surface of each test item receiving a Road Oyl spray application was first sprayed with approximately 1 gal of water per square yard. The water removed any dust from the surface and aided Road Oyl penetration into the sand-fiber surface. The Road Oyl was then applied using a 30-gal paint pot and air pressure. The Road Oyl was pumped through a garden hose containing an ordinary spray nozzle using 15 psi air pressure. The 40 sq yd surface area of each item was divided into thirds using string lines, and the measured quantities of Road Oyl were uniformity sprayed on each section as shown in Figure 36. When applied full strength (no dilution with water) the Road Oyl (at an application rate of 1 gal per square yard) penetrated approximately 1 in. into the sand-fiber surface. The Road Oyl was diluted with water for application on items 1A and 2A in order to aid penetration into the already partially stabilized sand-fiber/Road Oyl surfacing. Test items 1 and 2 contained no Road Oyl.

Completed test section

The completed test section is shown in Figure 37. Item 1 is on the right and item 4 on the left in the foreground of Figure 37. The painted lines on items 1 through 3 (on the right) are guides for applying the traffic pattern. All traffic wheel loads were applied between the two white lines in the center portion of each test item according to the pattern in Figure 19. A well-graded crushed stone base material was used as shoulders (2 ft wide) on the outside test section edges and in the area between the two test lanes (5 ft wide). The crushed stone base served to support load cart tires that would have to run in these locations. The crushed stone material between the test lanes was sloped to match a 4-in. height deferential between lanes 1 and 2. Since the entire test section was constructed above ground level, sand shoulders were extended 4 ft past the crushed stone shoulders to help prevent lateral movement of the test items during traffic tests.

Behavior of Test Section Under Traffic

Application of traffic

Simulated C-130 aircraft traffic. Test traffic was applied using a 30-kip single-wheel-assembly test cart shown in Figure 38. The cart was equipped with an outrigger wheel to prevent overturning and was powered by the front half of a four-wheel-drive truck. The test wheel and tire were the type used for a C-130 aircraft. The tire was inflated to 100 psi. The tire load was 30,000 lb with a contact area of 309 sq in. The measured tire contact width was 14.25 in. and length was 25.5 in. Test traffic was applied by driving the test cart (approximately 4 to 5 miles per hour) forward and then in reverse over the entire length of the test section in the same wheel path. The load

tire was then moved over one wheel width and traffic continued. This procedure was followed using the lateral traffic distribution pattern shown in Figure 19 until the loading pattern was completed. The loading cycle was then repeated until 1,000 traffic passes were applied. Figure 39 shows a closeup view of the load tire on item 1.

Failure criteria

Failure criteria for unsurfaced or gravel surfaced pavements is 3 in. of rutting. In emergency situations C-130 aircraft can operate in much deeper ruts than 3 in. For this study, maintenance on test items was performed when rut depths reached approximately 3 to 4 in.

Maintenance

The surface of test items 1 and 2 contained no Road Oyl stabilizer. As the moist sand-fiber surface of these items dried during traffic, the load cart tires and test load tire would pull the fibers out of the sand surface. This problem did not occur when the surface was kept moist by spraying with a garden hose twice a day.

Small amounts of sand-fiber (used in item 2) or sand-fiber-Road Oyl (used in items 3, 5, and 6) patching material were used to repair spot locations where 3- to 4-in. ruts developed. Figure 40 shows how some patching material was used to repair a spot rut that developed at the transition between items 2 and 3. A pitch fork worked much better than a shovel when handling the patch material. The fibers prevent a shovel from penetrating into a pile of patch material. Figure 41 shows the patched area after traffic compacted the patch. The patched area bonded with the item surface and stayed in place during additional traffic passes. Patching sand-fiber layers with like material was easy and effective.

Rut depth measurements

Rut depth measurements were recorded at intervals throughout the traffic test period. Rut depth measurements were made by placing a metal straight edge across the traffic lane at three locations in each item (item quarter points) and measuring the maximum rut depth using a ruler. The rut depth included both the permanent deformation and upheaval within the traffic lane. The average of the three readings was recorded as the average rut depth for a given traffic pass level.

12-in.-thick items, lanes 1 and 1A. Rut depth measurements for these items are shown in Figure 42. Rutting for items 1 and 2 (wet sand-fiber surfacing) was about the same. Both items had rut depths of 3 to 4 in. after only 200 passes and no significant increase in rut depth from 200 to 1,000 passes. When the 4-in. surfacing of these items was reconstructed to form items 1A and 2A (sand-fiber/Road Oyl surfacing), rut depths were

under 2 in. after 1,000 passes. Although some of the reduced rutting of items 1A and 2A were probably due to increased compaction of the sand subgrade by the first 1,000 traffic passes, a significant amount of the rut depth reduction was due to the small amounts of Road Oyl that was incorporated into the 4-in.-thick surfacing. Since the only difference in items 1 and 2 (also 1A and 2A) was the sand grid in items 2 and 2A, rut depth plots in Figure 42 shows no increase in performance due to the sand grid.

8-in.-thick items, lane 2. Rut depth measurements for these items are shown in Figure 43. Item 4 (8-in. sand-fiber with Road Oyl spray-on surfacing) averaged 5 in. of rutting after only 25 passes. On the 25th pass, the load tire sheared the sand-fiber layer causing the load cart vehicle to become stuck (Figure 44). Although rutting in items 5 and 6 was slower to develop, significant patching along the entire length of each item was required to keep the load wheel from shearing through the center wheel path of the tracking lane.

Cross sections

Surface cross sections were recorded at intervals throughout the test traffic period. The cross sections of the traffic lanes were recorded at the same item quarter point locations where the rut depth measurements were made. One measure of traffic performance obtained from the cross-section data was the average maximum permanent surface depression (ignoring any upheaval). Typical cross-section plots at various traffic pass levels were also useful in describing the performance of test items.

Permanent surface depression. Figures 45 and 46 show a record of the maximum permanent surface depression for all the test items. Each plot represents the average maximum surface depression based on the three cross-section locations for each test item. In general, the permanent surface depression plots follow the same pattern as the rut depth plots. The effects of a small amount of patching material (approximately 1 to 2 cu ft per item) on permanent depression can be seen for items 2 and 3 in Figure 45. Only small amounts of patching material (same material used in item surfacing) was needed to stabilize or retard further increases in permanent depression with additional traffic passes. However, in item 5 (Figure 46) a large quantity of patching material (approximately 10 cu ft) was required to reduce the permanent depression.

Typical cross sections of permanent deformations. Figures 47 through 55 show typical cross sections of permanent deformations of the various test items at various pass levels. Figures 47 through 49 for items 1 through 3 show that a lot of deformation occurred within the traffic lane and very little upheaval (negative deformation) occurred within or outside the traffic lane. This permanent deformation pattern indicates that most of the deformation was a result of increased densification of the sand-fiber base layer or subgrade sand due to the traffic loads. Figures 50 through 52 for items 1A through 3A show little upheaval and smaller amounts of permanent deformation than items 1 through 3. Some of the performance improvement of items

1A-3A over items 1-3 was probably due to the increase in base and subgrade compaction caused by traffic loads on items 1-3. Figures 53 through 55 show the permanent deformations for the 8-in.-thick items 4 through 6. Figure 53 shows the poor condition of item 4 after only 18 passes. The load cart sheared through this item on the 25th pass and became immobilized. Figure 54 shows the permanent deformation in item 5. The center wheel path of this item was patched the full length of the item after 126 passes. Upheaval outside the traffic lane on the west side after 180 passes was caused by rutting in the subgrade under the 8-in.-thick sand grid layer. Figure 55 shows the deformation pattern for item 6. The permanent deformation data showed that all the 8-in.-thick items were too thin to support the tire loads applied.

After-traffic photos

Figures 56 through 61 show the condition of each item after 1,008 passes of traffic. Even though items 1 through 3 had rutted over 3 in., their surface condition was still good with very little upheaval outside the traffic lane. The condition of items 1A through 3A was excellent after 1,008 passes. Rut depths in these items was less than 2 in.

Application of military truck traffic

After the C-130 load cart tests were completed, truck traffic was applied to test items 1A through 3A and items 5 and 6. A 5-ton military cargo truck loaded to a gross weight of 41,600 pounds was used. A total of 120 truck passes were applied to items 5 and 6 and 1,000 passes were applied to items 1A through 3A. Figure 62 shows the truck on item 1A and Figure 63 shows the condition of item 1A after 500 truck passes (item 1A looked the same after 1,000 passes). A uniform traffic distribution was applied over the entire 12-ft-wide test surface in items 1A through 3A. The truck traffic was beneficial in that it smoothed out the rutting caused by the load cart tests. Items 1A through 3A could have supported substantial amounts of additional truck traffic. Figure 64 shows the truck on items 5 and 6 after 120 passes. These limited test results indicated that the 8-in.-thick items could easily support large amounts of truck traffic. Test results also indicated that a simple spray-on application of Road Oyl makes an excellent wearing surface for sand-fiber base layers for truck traffic.

Analysis and Conclusions

The following analysis and conclusions are based on tests with one type of sand and one fiber length and type. The tests did not include braking or turning traffic conditions. The fiber content and Road Oyl requirements may change for different sand types.

Thickness requirements

C-130 aircraft. Figure 65 shows the results of rutting versus passes for load cart traffic on the 8-in. and 12-in.-thick sand-fiber items tested. The 8-in.-thick sand fiber (item 4) was too thin to support any significant amount of C-130 type traffic. The 12-in.-thick sand-fiber (item 1) supported the traffic for 1,000 passes with rut depths averaging 3.5 to 4.0 in. When the top 4 in. of the sand-fiber layer was lightly stabilized with Road Oyl (item 1A), rut depths were kept less than 2 in. after 1,000 passes. All significant rutting occurred within 200 traffic passes. Rut depths at 1,000 passes were about the same as they were at 200 passes. Based on the tests conducted, for sand-fiber stabilization over a sand subgrade (medium to coarse sand), the stabilized thickness requirements should be 12 in. This thickness should support over 1,000 C-130 aircraft passes.

Truck traffic. Based on the limited truck traffic tests, an 8-in.-thick sand-fiber layer is sufficient to support substantial amounts of military truck traffic.

Surfacing

C-130 aircraft. Based on the performance of items 1A, 2A, and 3A, stabilizing the top 4 in. of the sand-fiber layer with Road Oyl was sufficient in providing a wearing surface that kept rut depths to less than 1.6 in. after 1,000 passes (see Figure 45). The amounts of Road Oyl tested ranged from 0.3 to 1 gal per square yard (gsy) per inch of depth (based on undiluted quantities). The higher quantity of Road Oyl produced a solid asphalt-concrete type surfacing that should provide for better breaking and turning performance. For best results, the Road Oyl should be admixed into the sand-fiber material using a self-propelled rotary mixer. For adequate traffic performance, it is recommended that 2 to 4 gsy of undiluted Road Oyl be admixed into the top 4 in. of the sand-fiber base layer and compacted using a smooth drum vibratory compactor.

Truck traffic. A spray-on surfacing of Road Oyl (1 gsy undiluted) penetrates approximately 1 in. into the sand-fiber surface and provides an excellent wearing surface for truck traffic. The top 1 in. of the sand-fiber surface should be moist to aid the penetration of the sprayed-on Road Oyl.

Compaction requirements

C-130 aircraft. The only compaction applied to the 18-in.-thick sand subgrade was from the tracks of a D-4 tractor and front-end-loader during construction. The sand was too unstable to support the smooth drum vibratory compactor. Compaction using six passes of the smooth drum vibratory compactor on the 8-in.-thick sand-fiber layer and six additional passes on the 4-in.-thick surfacing may not have been sufficient to prevent consolidation of the subgrade sand during traffic tests. Figure 45 shows how items 1 through 3 had permanent depressions of about 3 in. after 200 to 400 load cart passes.

However, when the surfacing of item 3 was patched lightly and leveled to form item 3A, only slightly more than 1 in. of additional permanent depression resulted after 1,000 additional load cart passes. This indicates that the compaction applied to the surface of items 1 through 3 probably should have been greater. Heavy pneumatic-tire compaction in addition to the vibratory compaction probably would have further compacted the subgrade sand and improved the performance of items 1 through 3. For expedient pavement applications, the six passes of vibratory drum compaction should be adequate. Minor maintenance of filling and releveling ruts after 400 aircraft passes would produce a smoother surface which would prevent any significant future rutting.

Truck traffic. A total of six passes with the vibratory drum compactor was adequate for truck traffic.

Use of sand-grid

Sand-grid filled with sand (8-in.-thick layer used in items 3 and 3A) can be substituted for sand-fiber for C-130 pavement applications if surfaced with 4 in. of sand-fiber/Road Oyl surfacing.

Sand-grid filled with sand-fiber (Figure 42), items 2 and 2A did not offer any performance improvement over sand-fiber (Figure 42), items 1 and 1A.

Cost

Sand-fiber. Test quantities of fibers used in this study cost $1.40/lb. The cost of bulk quantities is not known, but should be substantially less. The cost of fibers to stabilize (using 1 percent fibers by dry weight of sand) a 12-in.-thick layer of sand was $1.54/sq ft of test surface.

Fiber for an 8-in.-thick road would cost $1.03/sq ft of road surface.

Road Oyl. Road Oyl costs $4.24/gal in 55-gal drums and would cost approximately $2.00/gal in bulk. Cost of stabilizing the top 4 in. of sand-fiber surface would be $0.94 to $1.88/sq ft of pavement surface (for 2 to 4 gal of drum Road Oyl/sq yd of pavement surface). If bulk quantities of Road Oyl are used, the cost would drop to $0.44 to $0.88/sf of pavement surface.

A road surface with 1 gal of Road Oyl/sq yd would cost either $0.22 or $0.47/sq ft of pavement surface depending on whether bulk or drum material was used.

Total material cost. Assuming the sand is in place, the total material cost for a stabilized 12-in.-thick sand-fiber pavement with Road Oyl surfacing would be $1.98 to $3.42/sq ft of pavement, depending on the quantity and type container used for the Road Oyl. For comparative purposes, the cost of AM2 Airfield Landing Mat is approximately $16/sq ft.

Cost for an 8-in.-thick sand-fiber road surfaced with Road Oyl would range between $1.25 and $1.50/sq ft.

Summary Conclusions

Based on the tests conducted, Figure 66 shows recommended stabilized sand-fiber pavement sections for C-130 aircraft and military roads over sand subgrades. Although not tested, a gravel surfacing or emulsified asphalt could probably be substituted for the Road Oyl.

5 Recommendations

Field Demonstration

Based on the results of this investigation, the monofilament fibers showed great potential for use in rapid stabilization of sandy soils. Field demonstration tests are needed to test sand-fiber stabilization performance under actual C-130 landing, takeoff, braking, and turning operations to obtain a better perspective of the benefit of this fiber. Field demonstration tests are also needed to test the durability and maintenance requirements for sand-fiber stabilized military roads.

Additional Research Needs

Results of this study show great potential for military airfield and road applications using sand-fiber stabilization techniques. Additional research must be conducted before design guidance for global applications is developed. Future research on sand-fiber stabilization should address the following:

a. Effect of sand type (only one sand type was studied in this work).

b. Effect of fiber length on construction and performance.

c. Other types of fibers (such as fibrillated fibers and recycled materials).

d. Surfacing stabilizers other than Road Oyl.

e. Traffic performance at reduced fiber contents.

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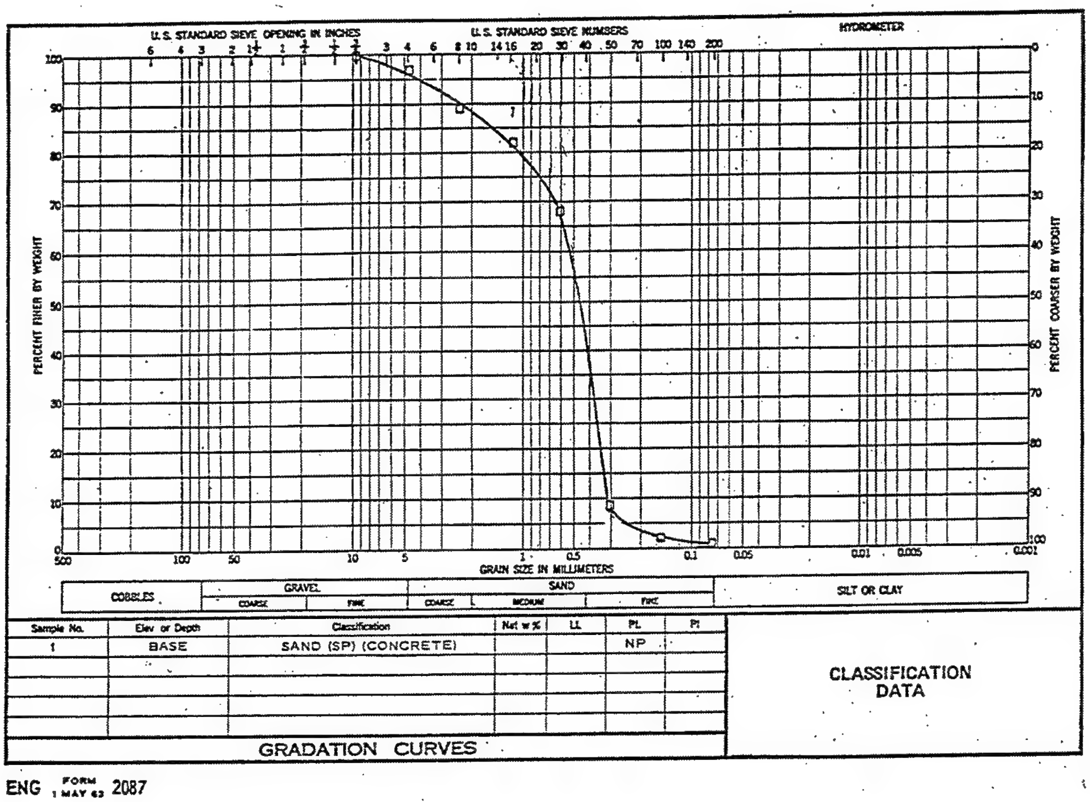

Figure 1. Sand classification data

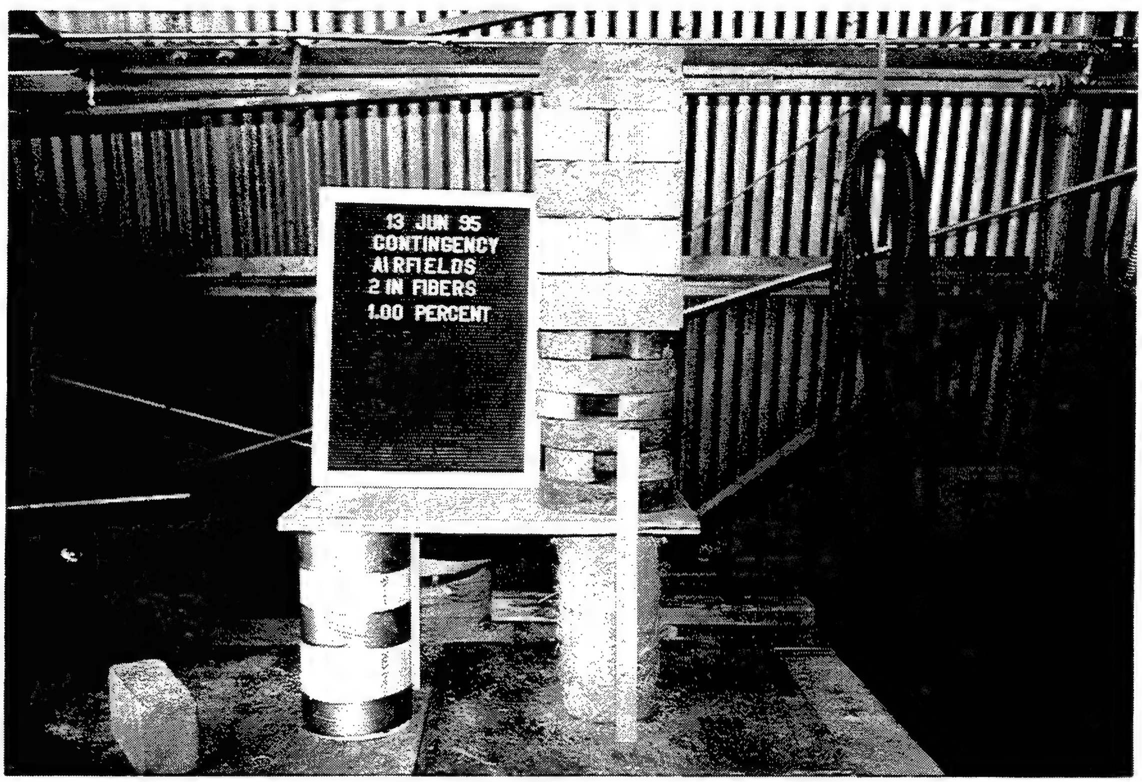

Figure 2. Sand-fiber sample with 201-lb loading

Figure 3. Monofilament fibers on sand surface

Figure 4. Field mixer equipment

Figure 5. Fiber mixed in sand after four passes

Figure 6. Close-up of sand-fiber mix

Figure 7. Sand-fiber ramps with 50,000-lb compactor

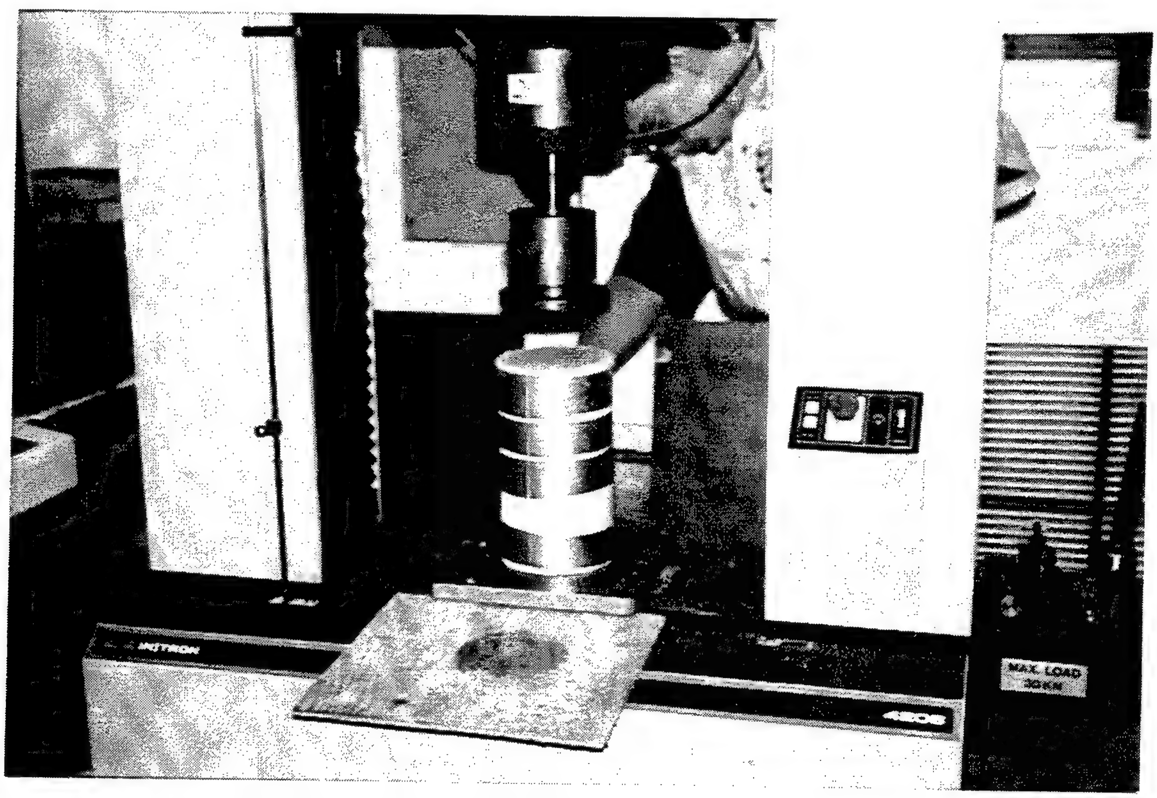

Figure 8. Sample preparation for unconfined compressive test

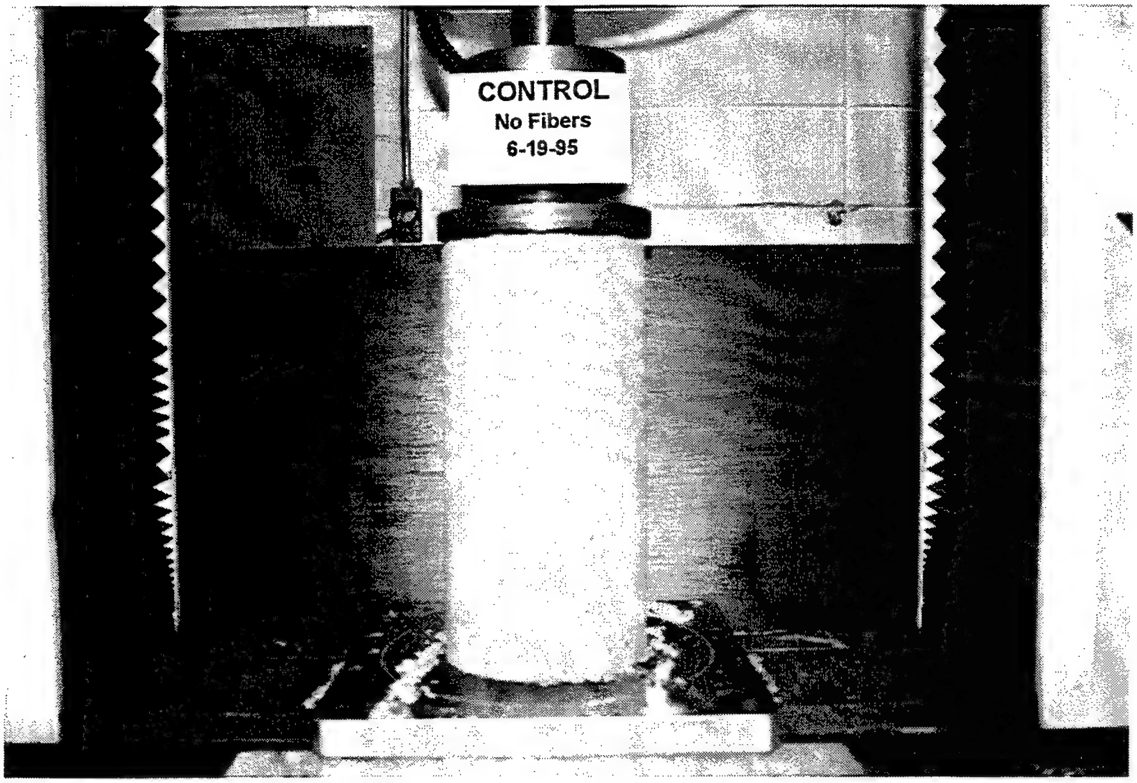

Figure 9. Control sample before loading

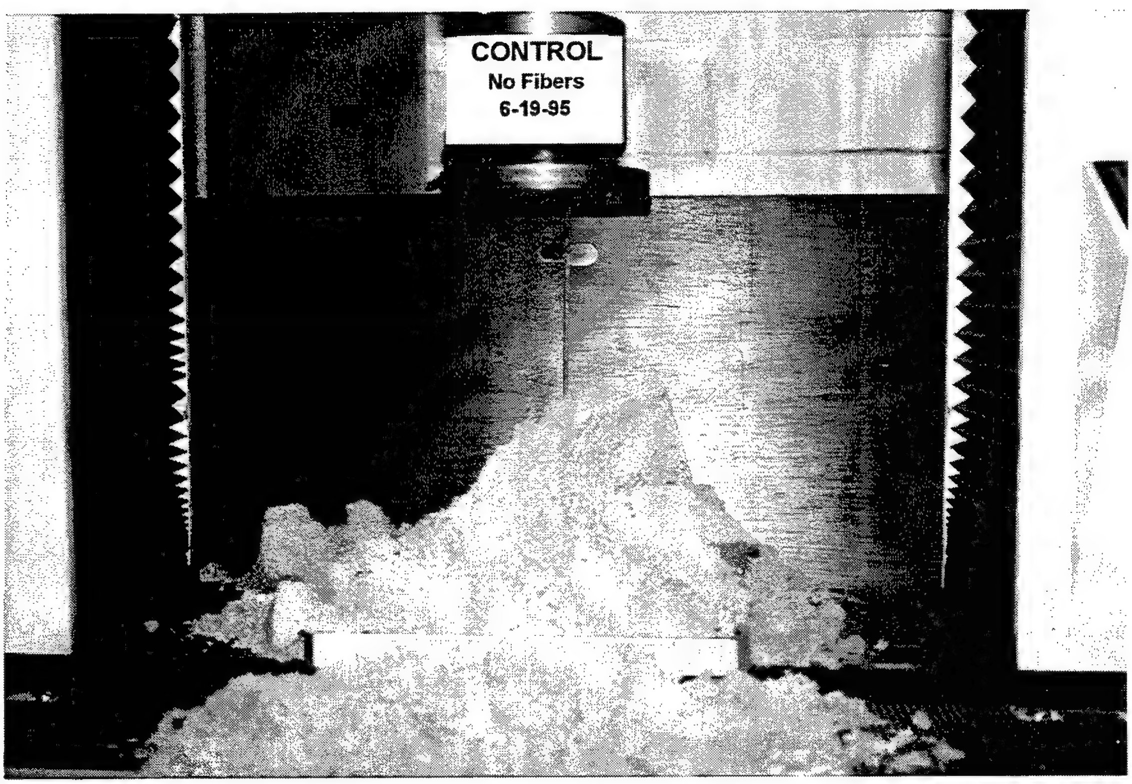

Figure 10. Control sample after 9.67-lb load

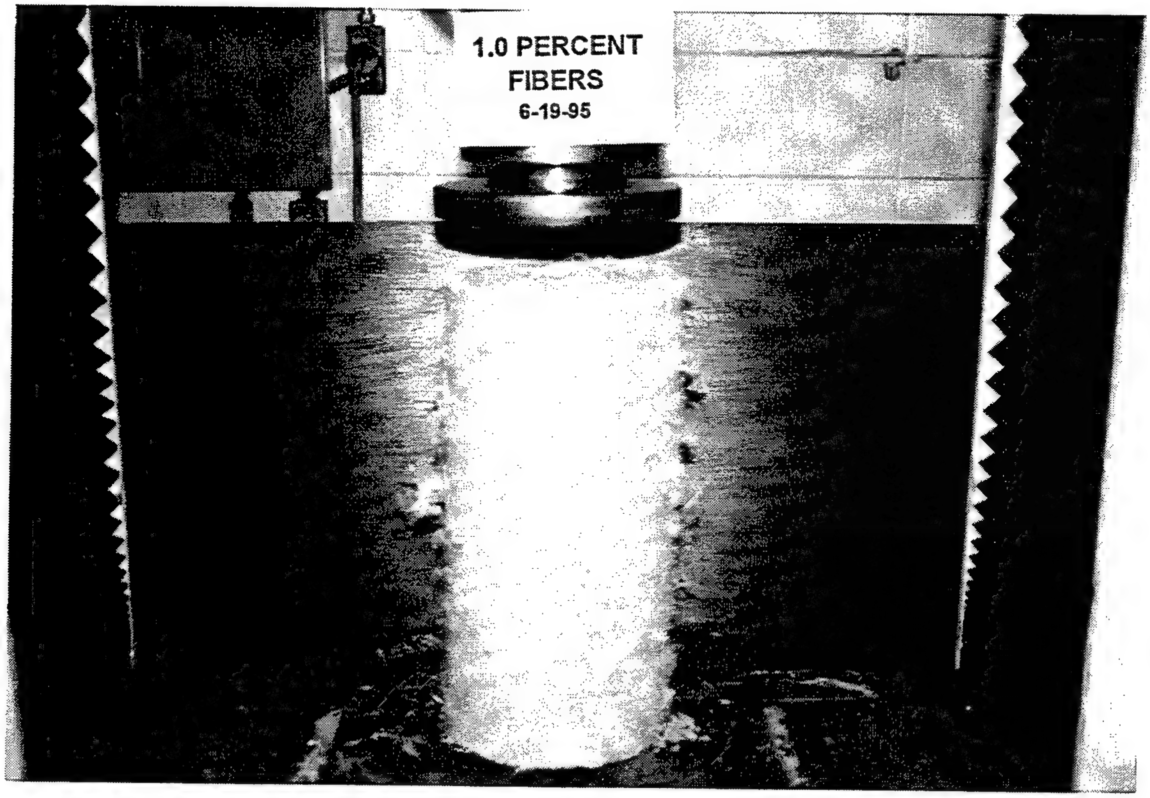

Figure 11. Sand-fiber sample with 1 percent of fiber before loading

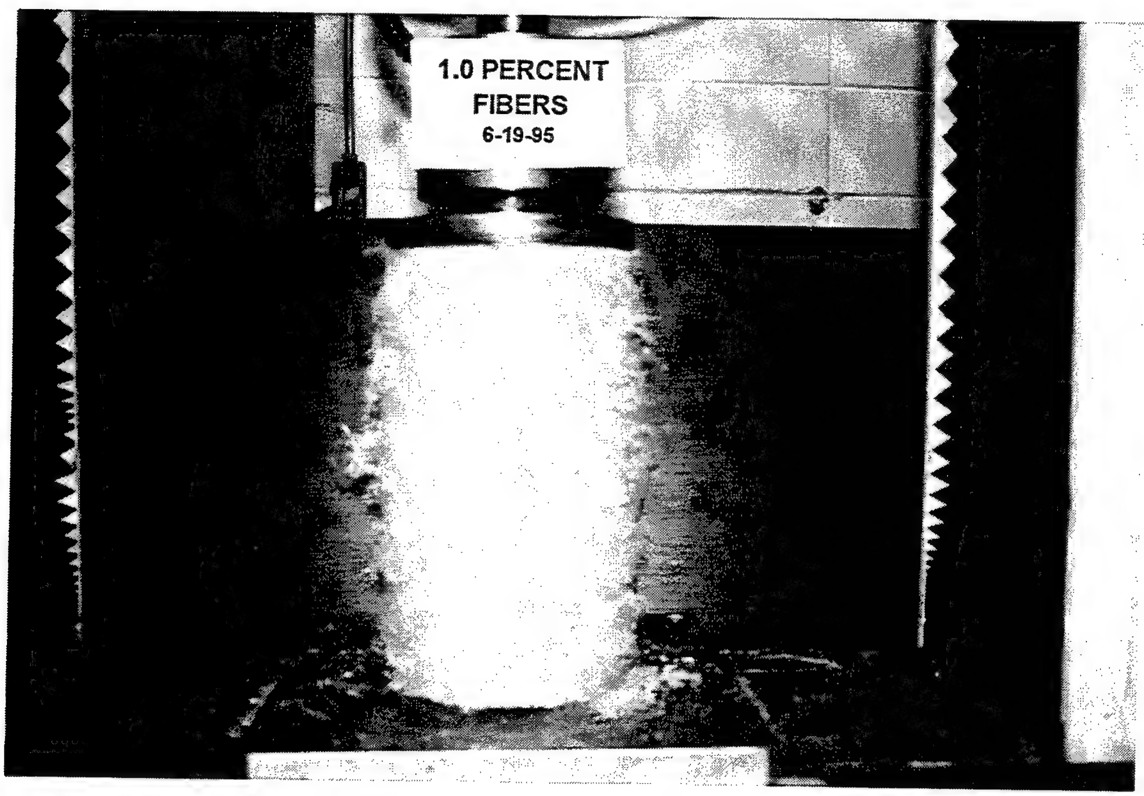

Figure 12. Sand-fiber sample (1 percent) after 750-lb load

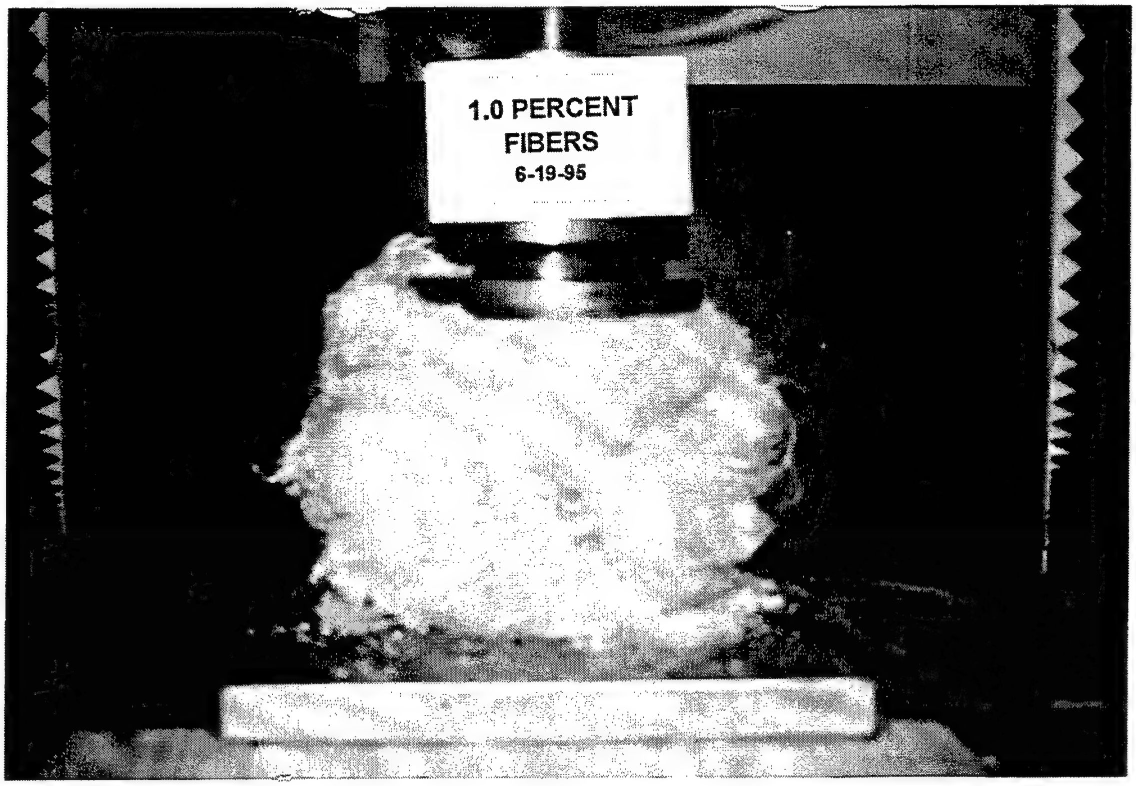

Figure 13. Sand-fiber sample (1 percent) after 4,000-lb load

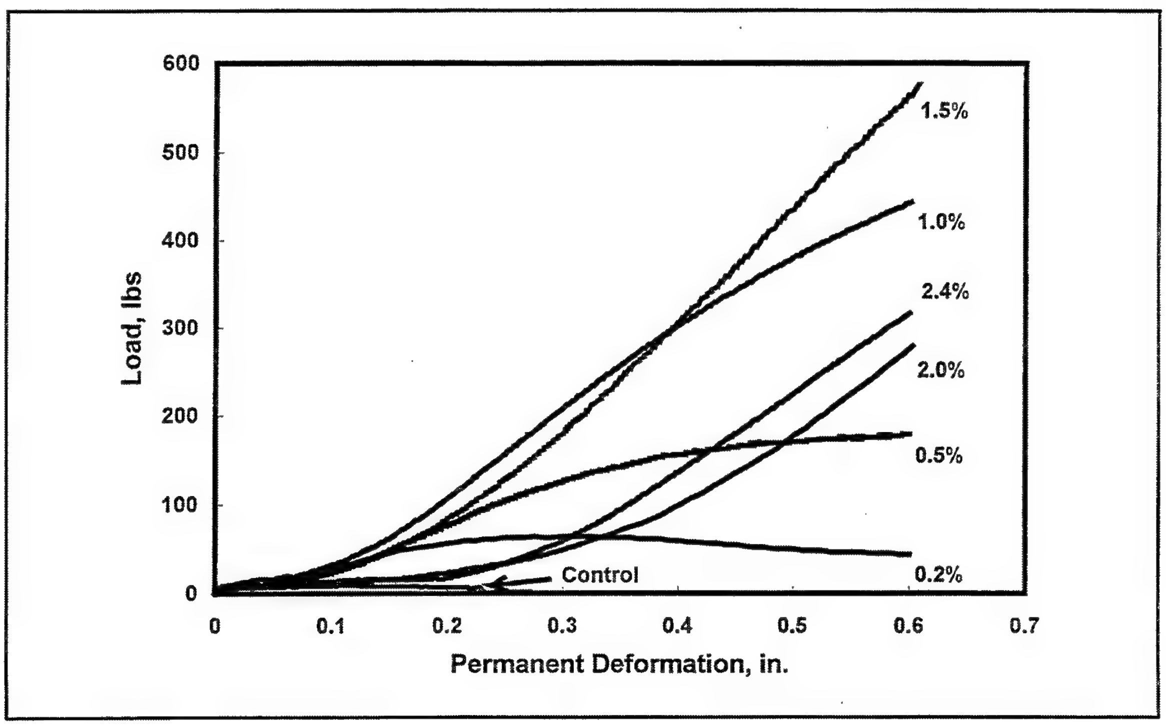

Figure 14. Relationship between percent of fiber and permanent deformation

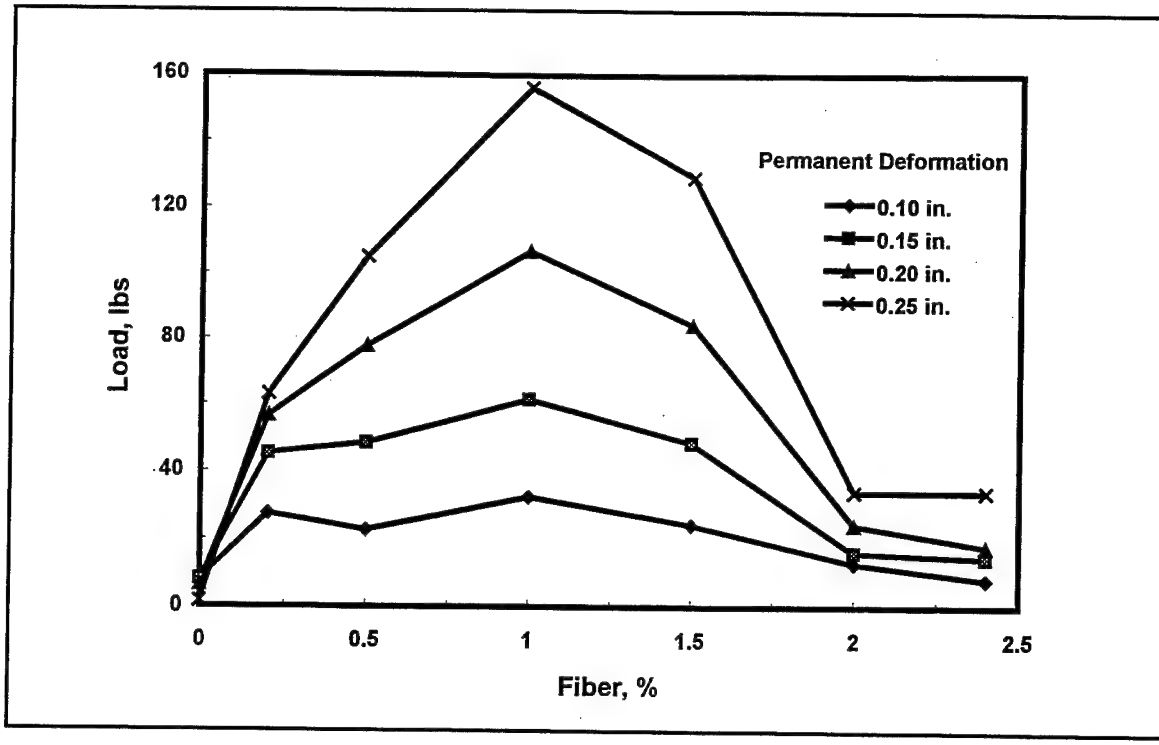

Figure 15. Optimum percent of fibers (0-to 0.25-in. deformation)

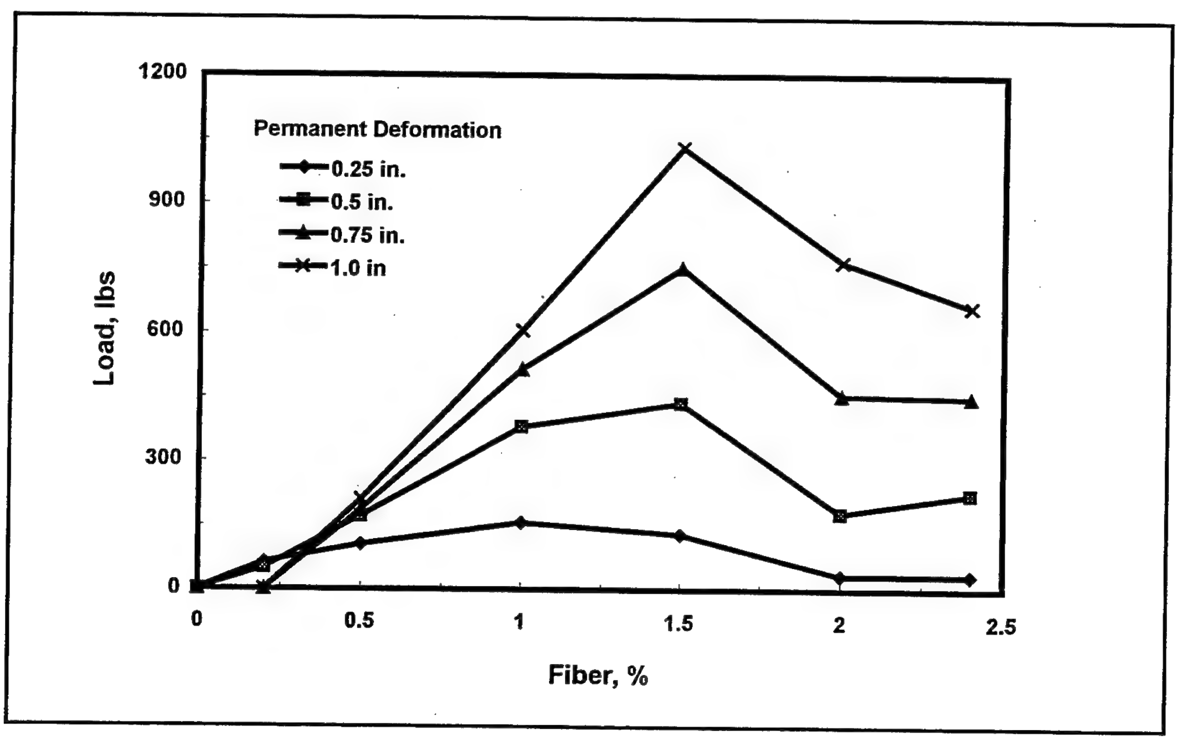

Figure 16. Optimum percent of fibers (0.25-to 1.0-in. deformation)

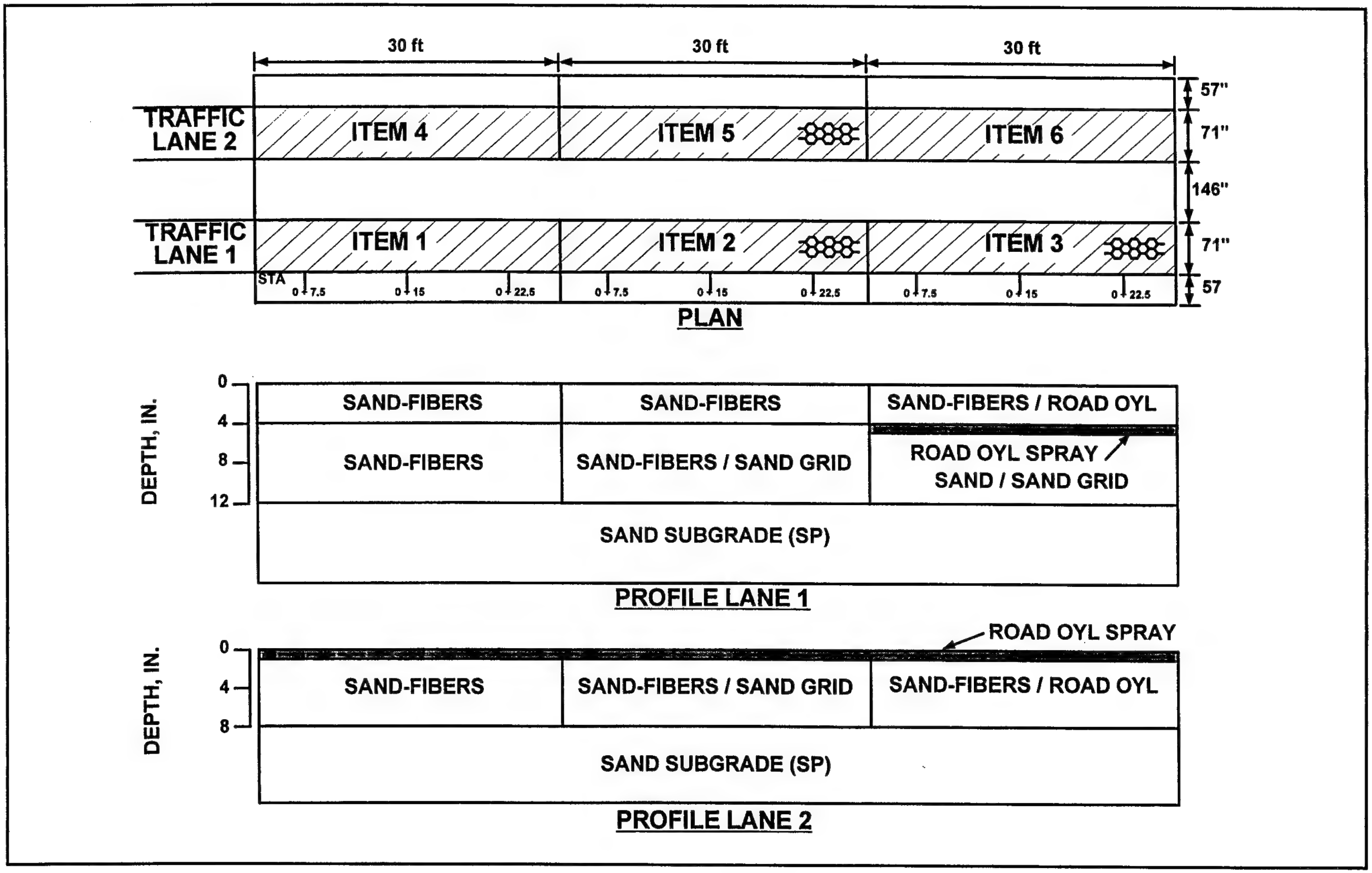

Figure 17. Plan and profile of test section, lanes 1 and 2

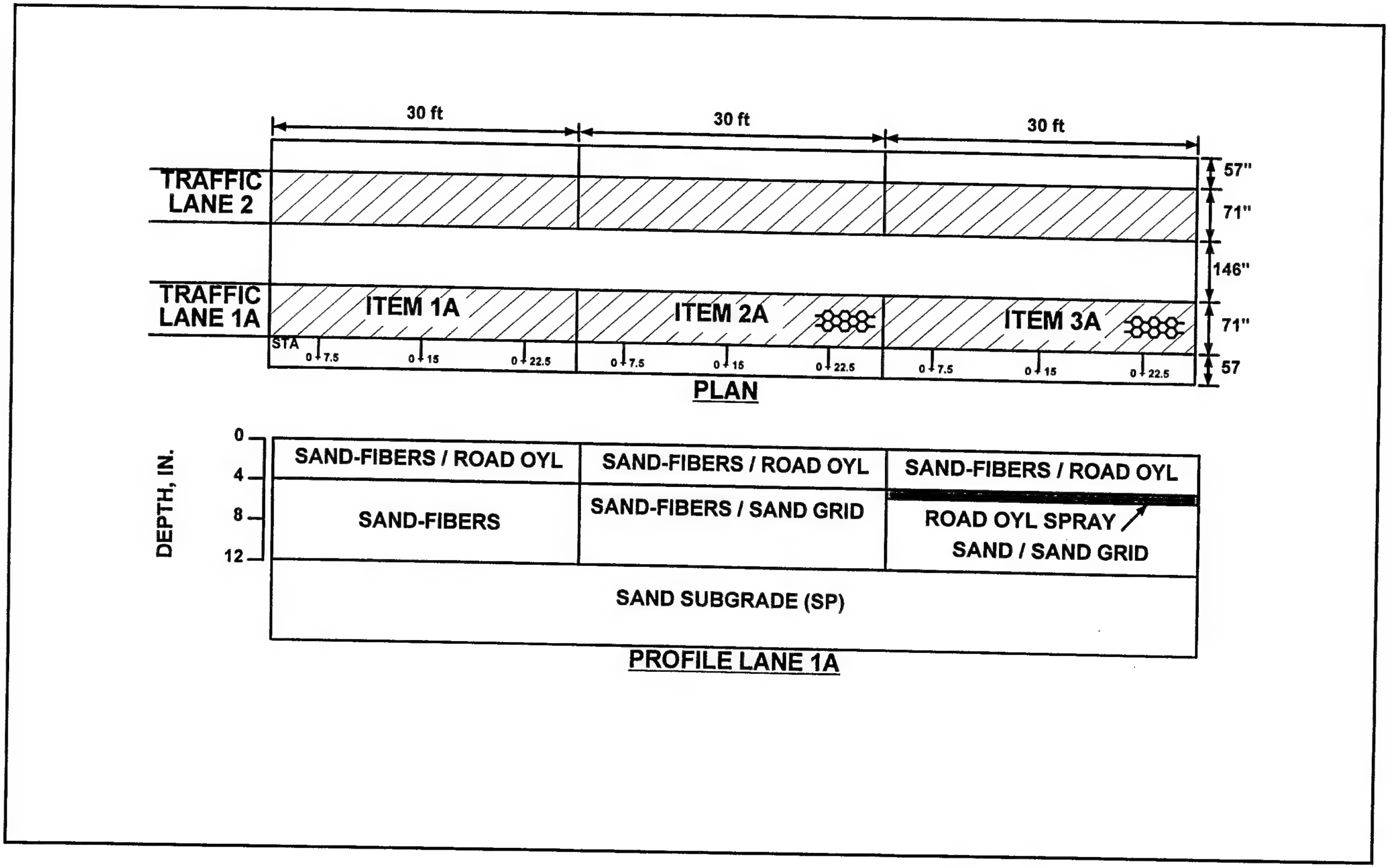

Figure 18. Plan and profile of test section, lane 1A

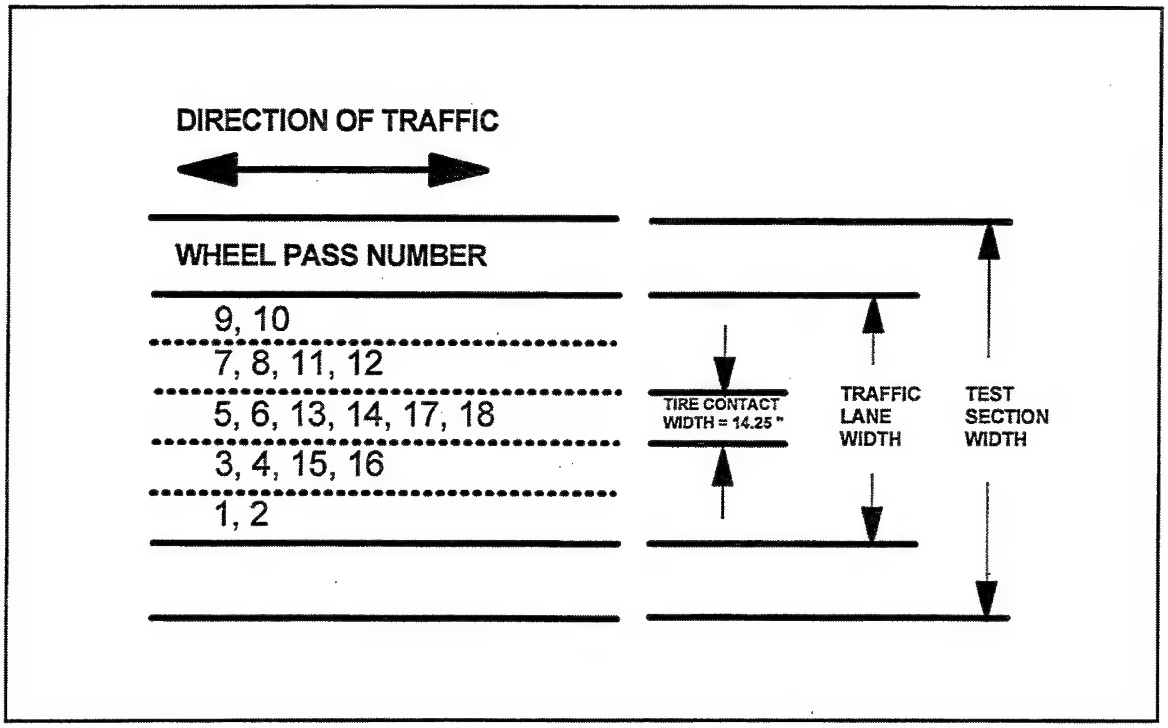

Figure 19. Traffic pattern for the single-wheel test cart

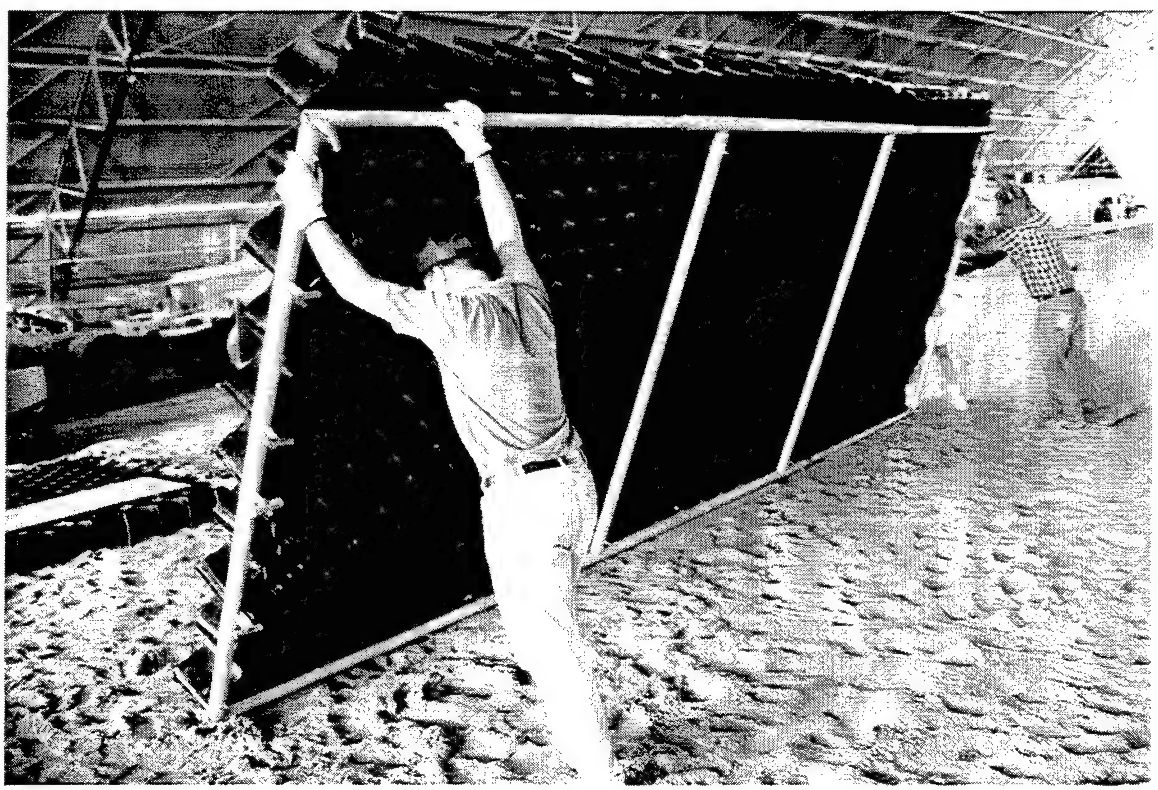

Figure 20. Sand grid installation using stretcher frame

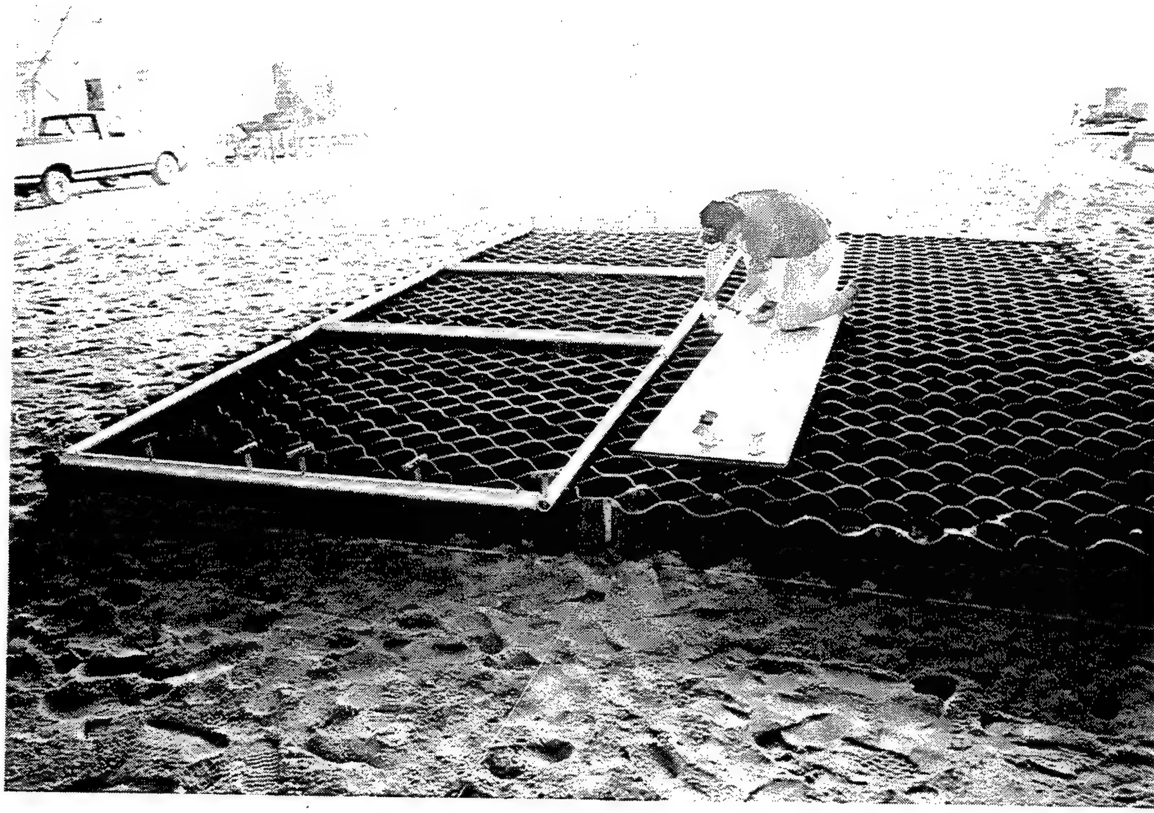

Figure 21. Connecting sections of sand grid using hog rings

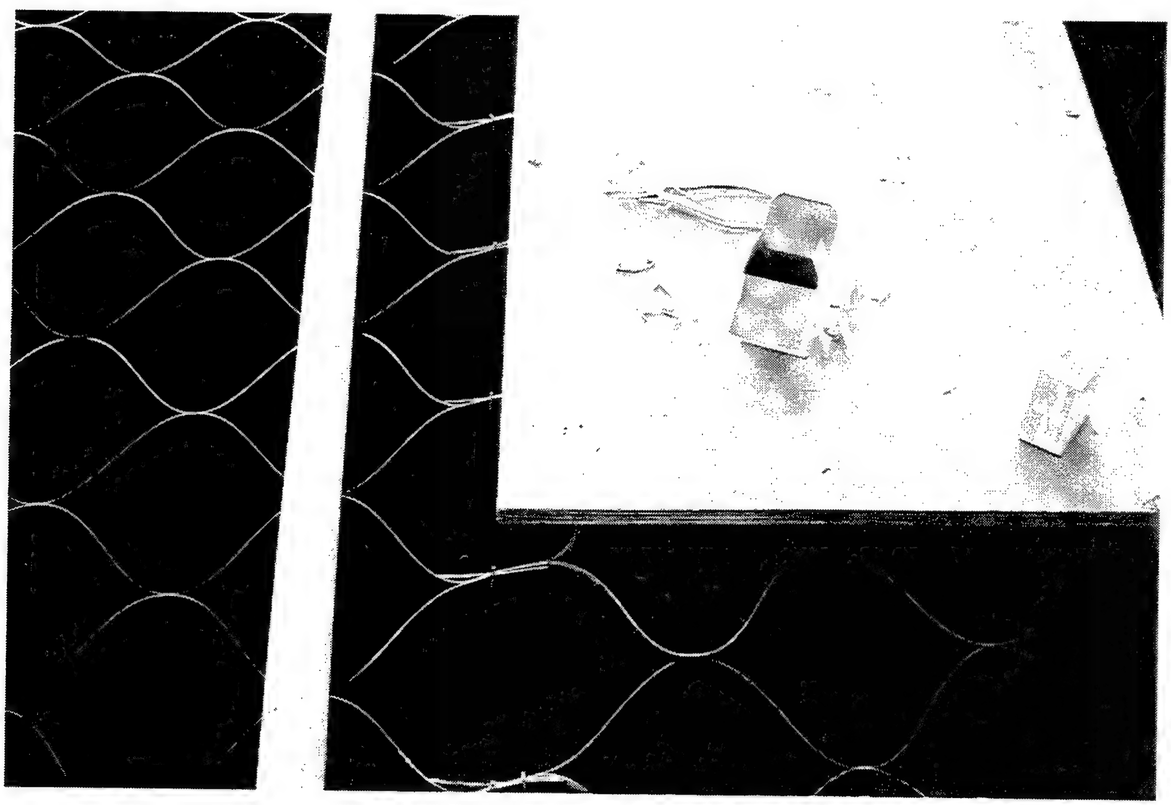

Figure 22. Close-up of hog ring connections

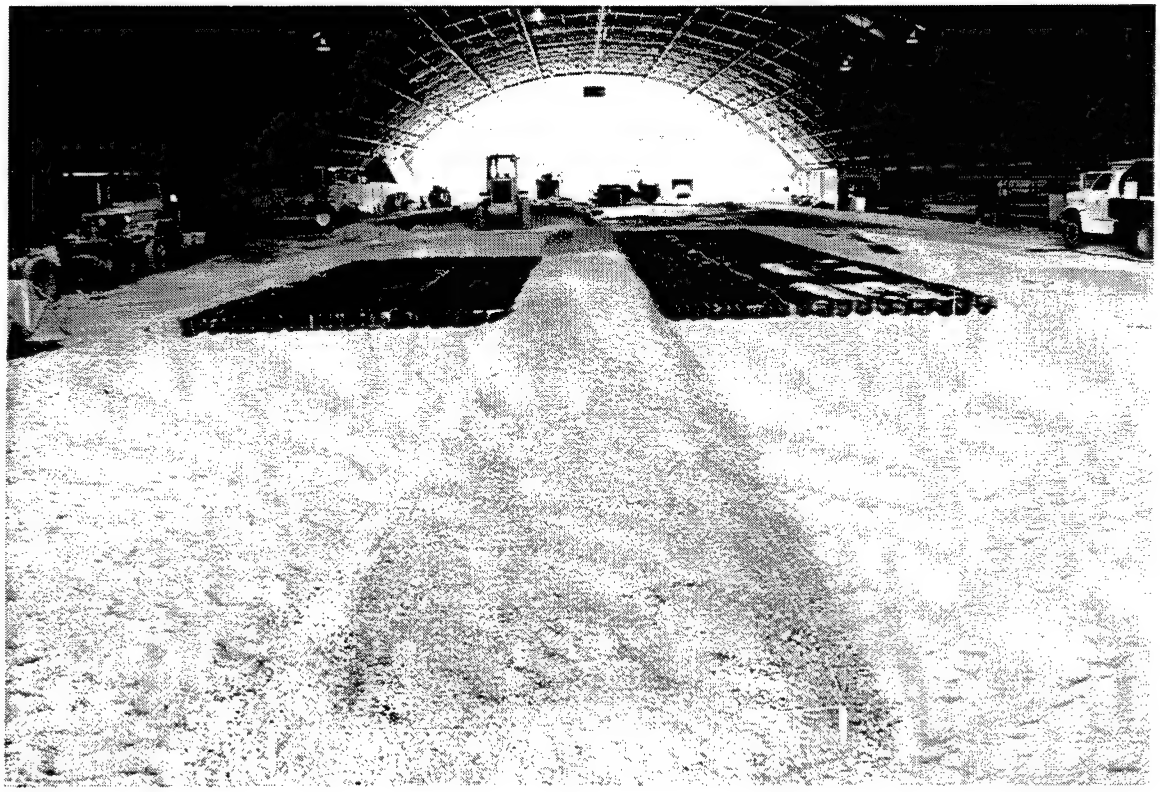

Figure 23. Completed sand grid installation

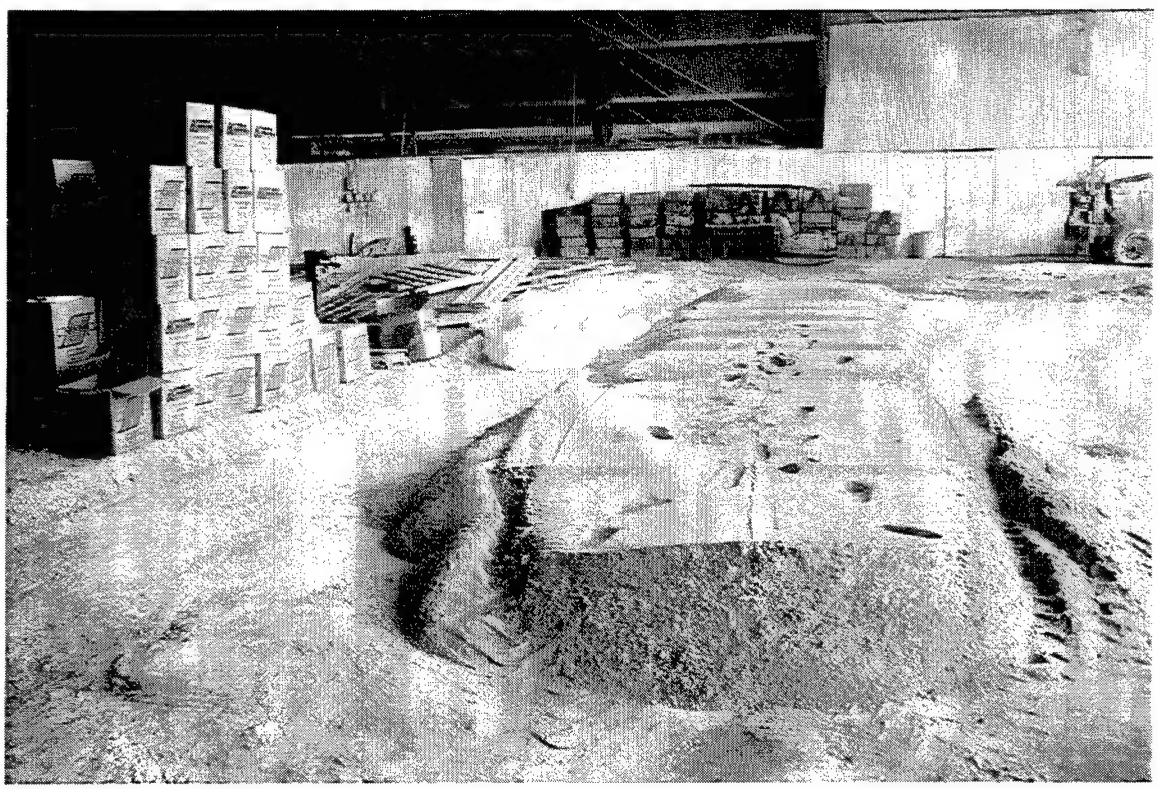

Figure 24. Sand for typical item, prior to adding fibers

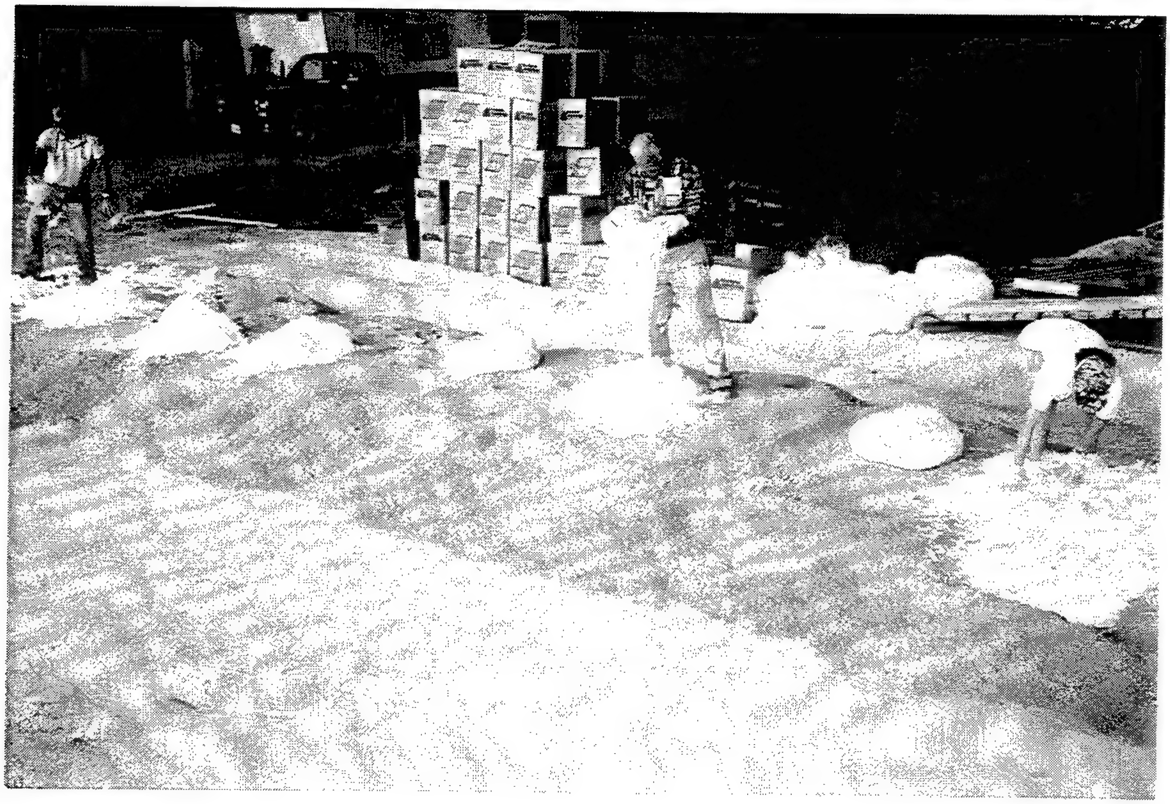

Figure 25. Spreading fibers on sand

Figure 26. Close-up of fibers on sand

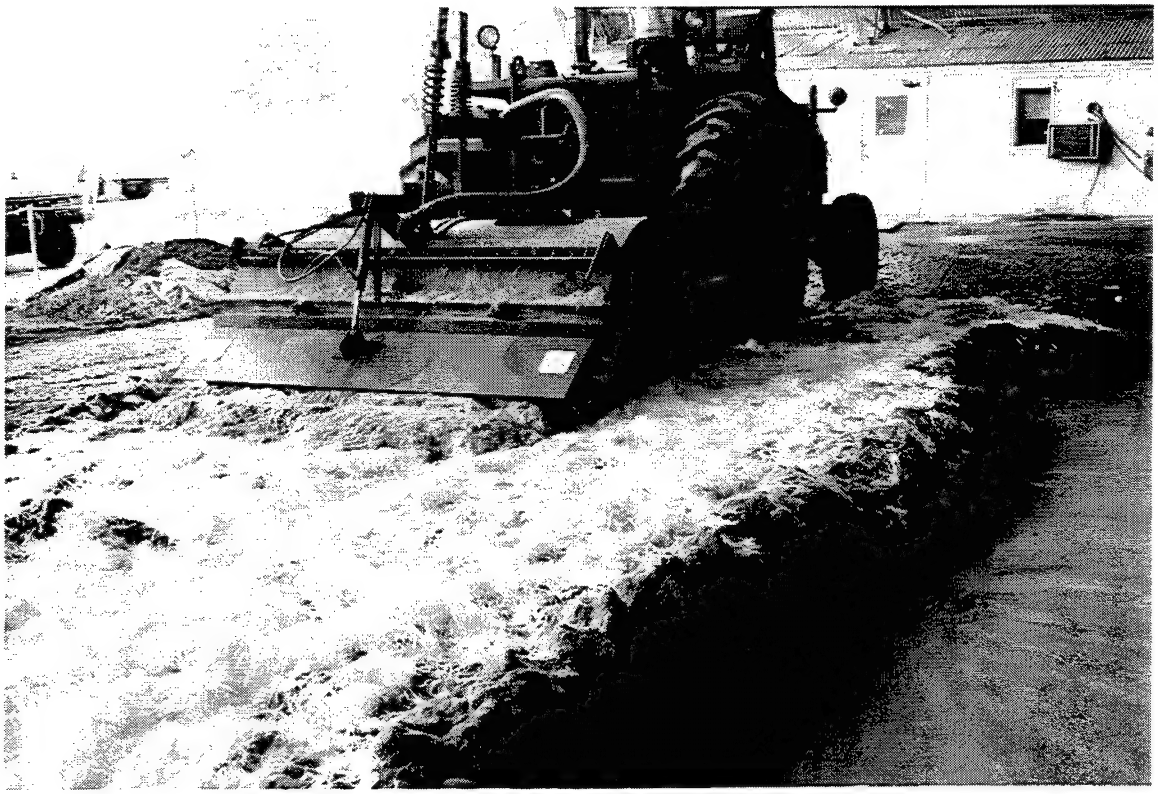

Figure 27. Mixing fibers into sand using rotary mixer

Figure 28. Sand-fiber mixture after four passes with mixer

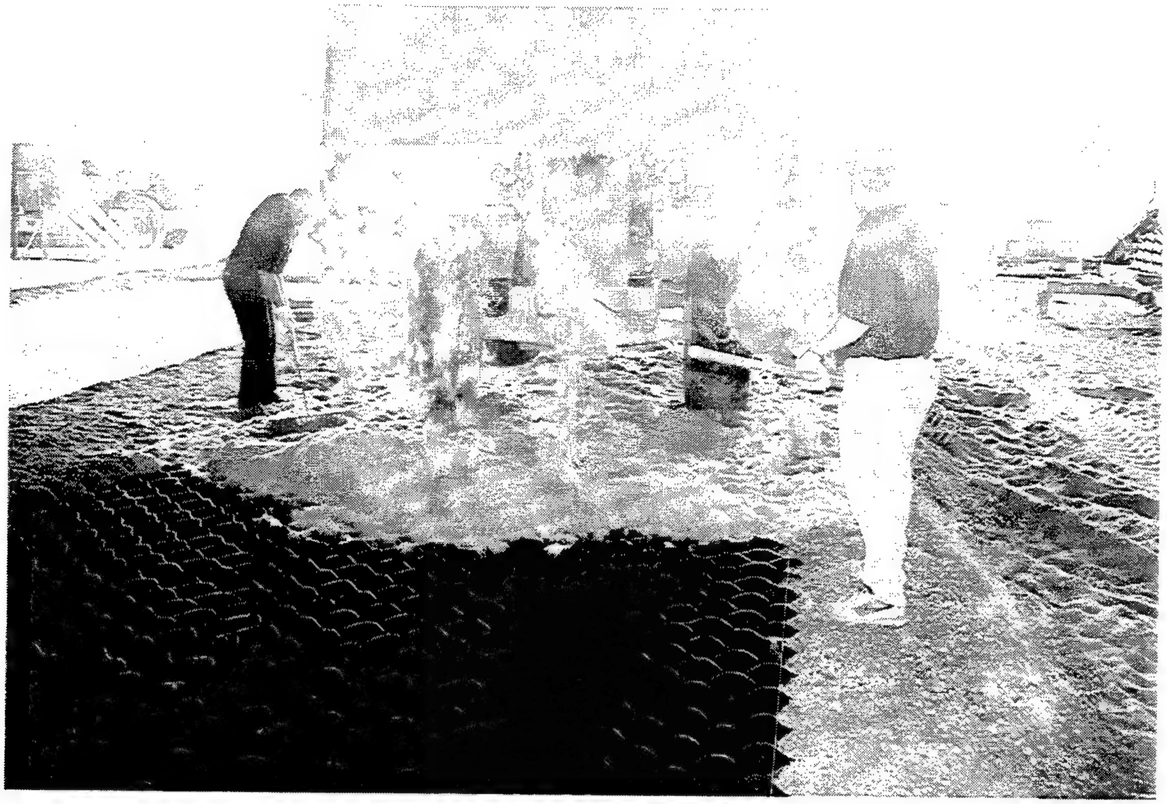

Figure 29. Installing sand-fiber mixture into sand grid

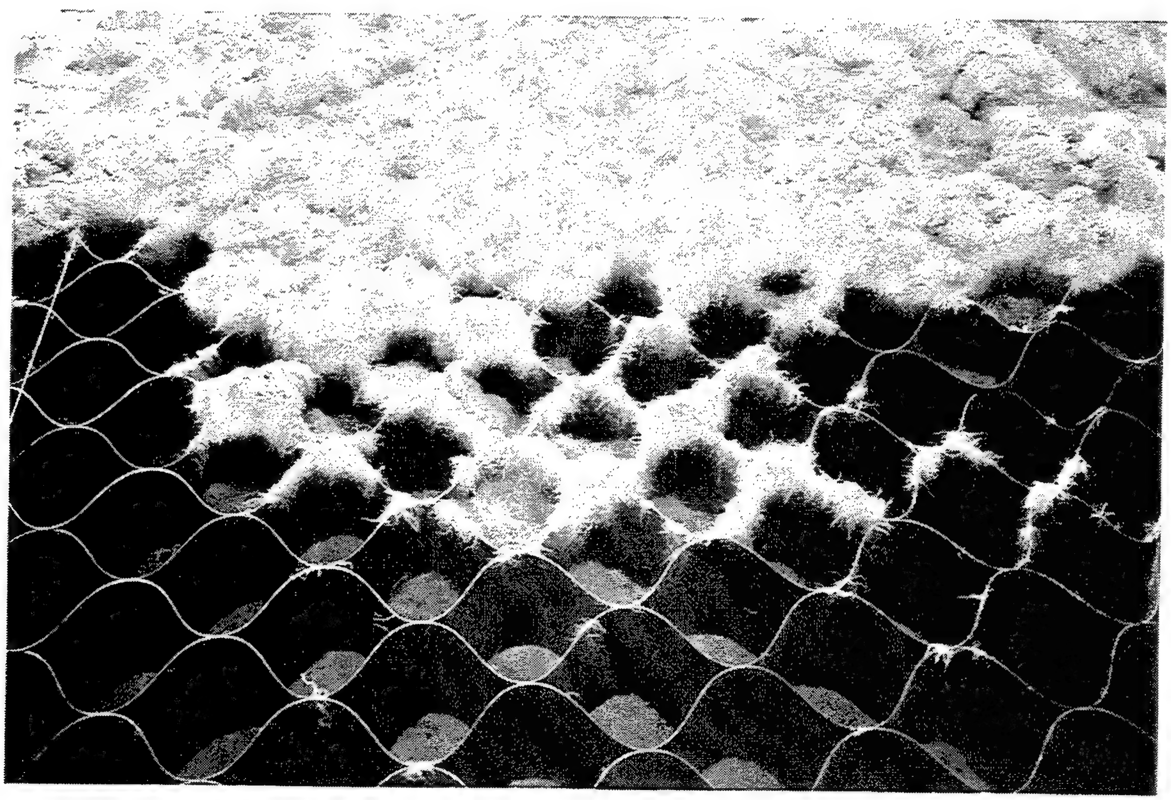

Figure 30. Close-up of fibers hanging up on sand grid cells

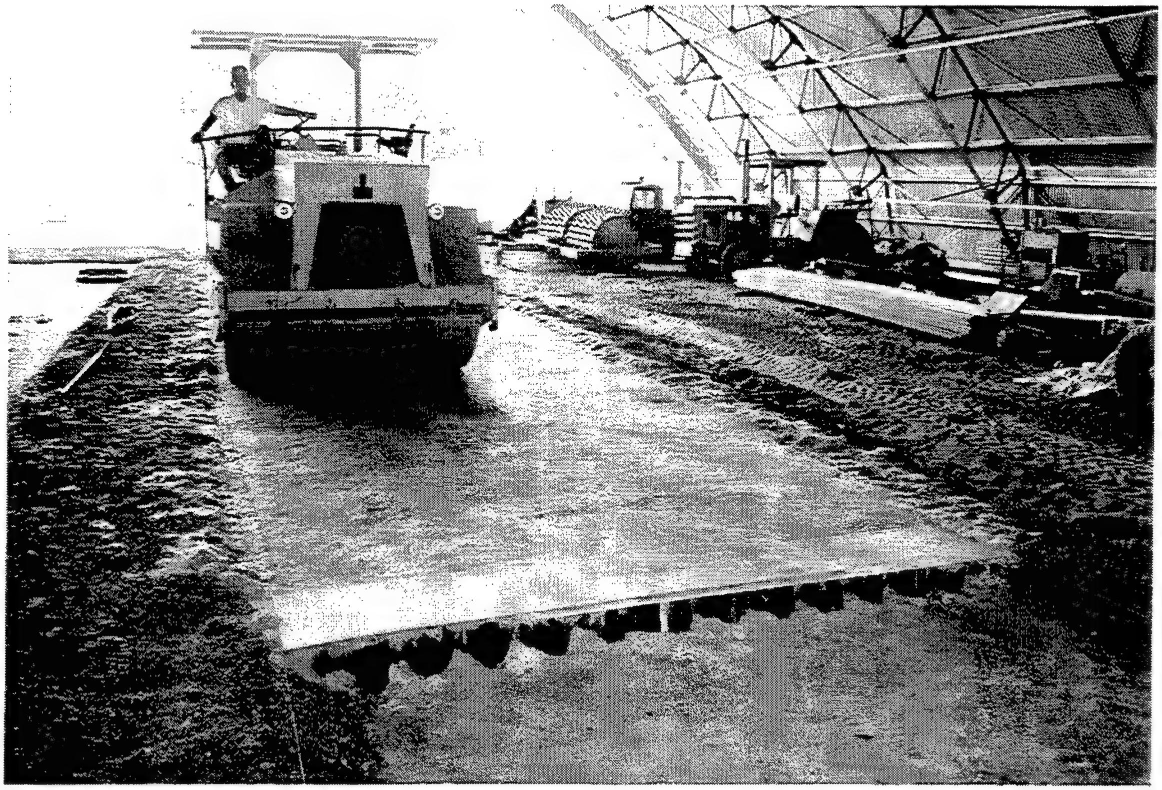

Figure 31. Compacting sand-fiber mixture into sand grid cells

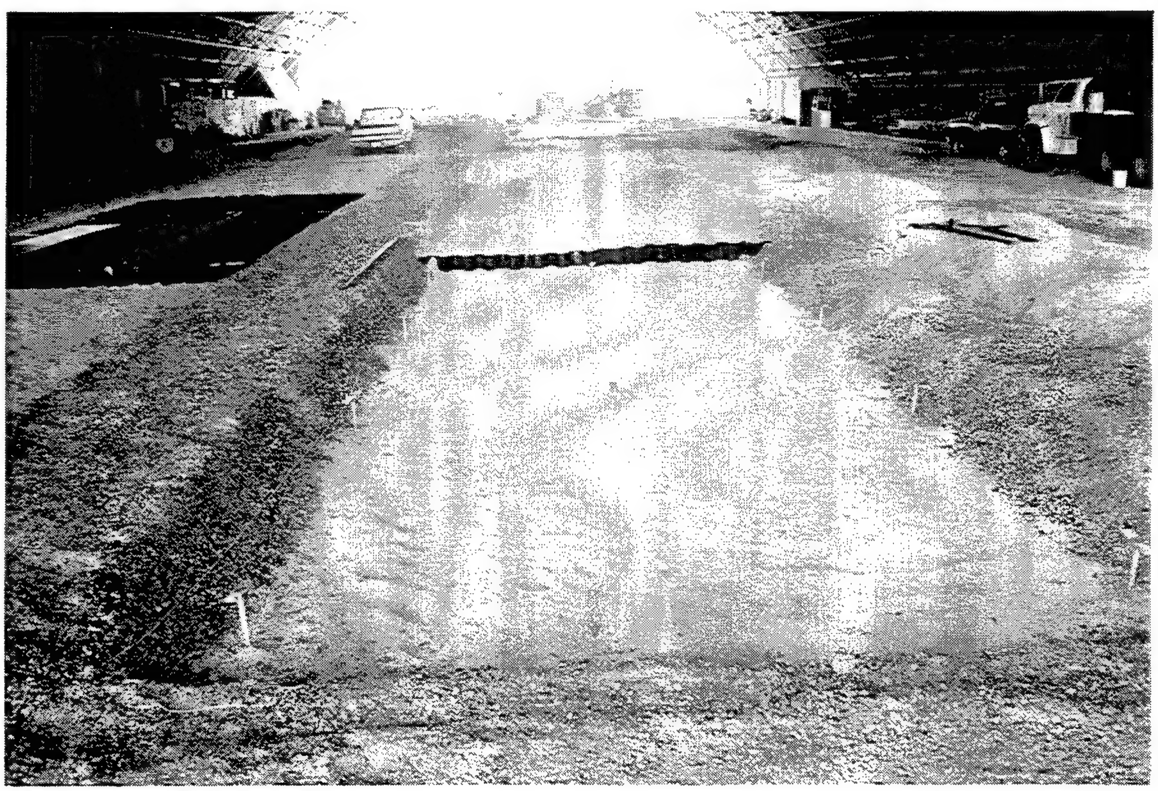

Figure 32. Item 1 before sand-fiber installation

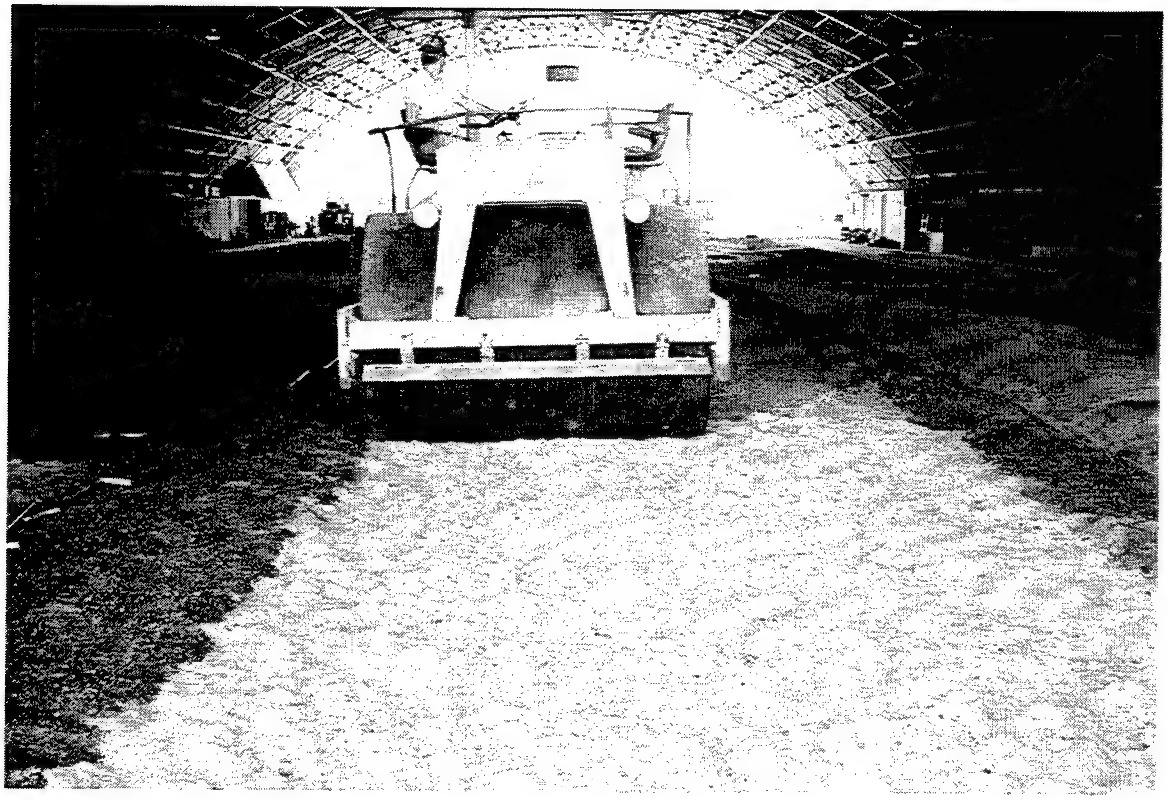

Figure 33. Sand-fiber surface prior to compaction

Figure 34. Adding Road Oyl on sand-fiber layer

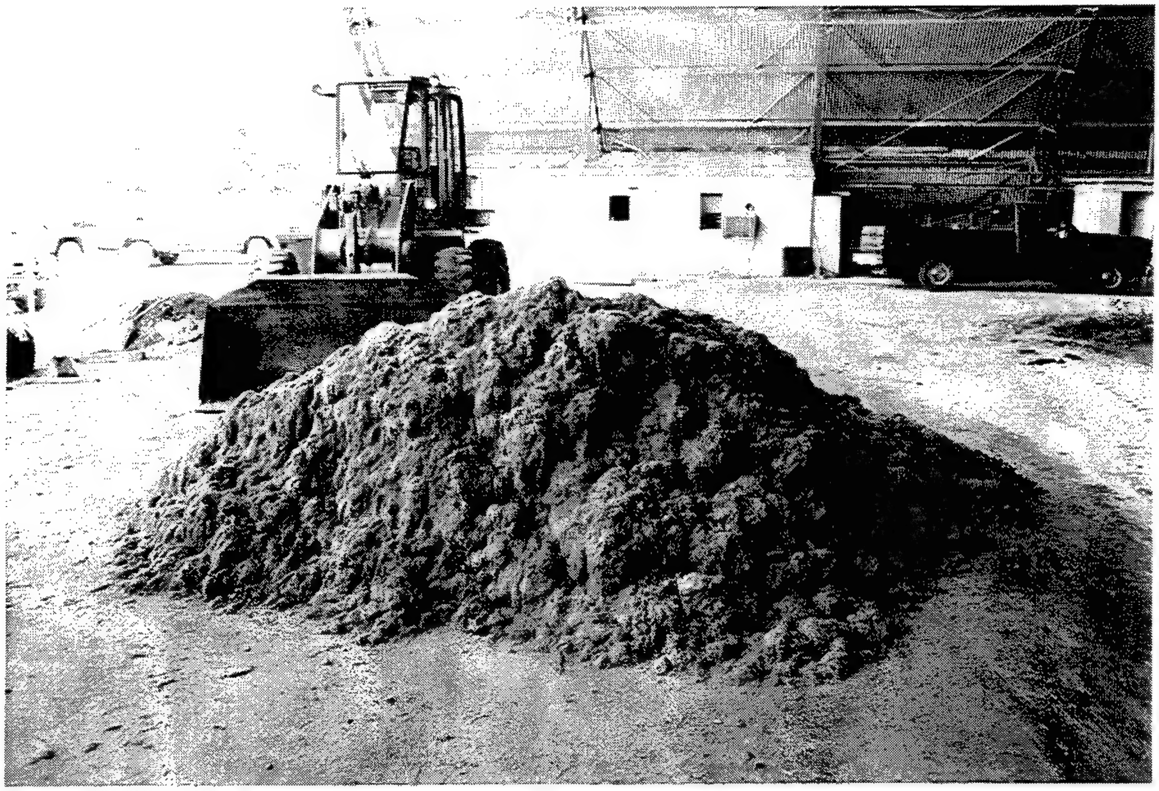

Figure 35. Mixture of sand-fiber and Road Oyl prior to installation

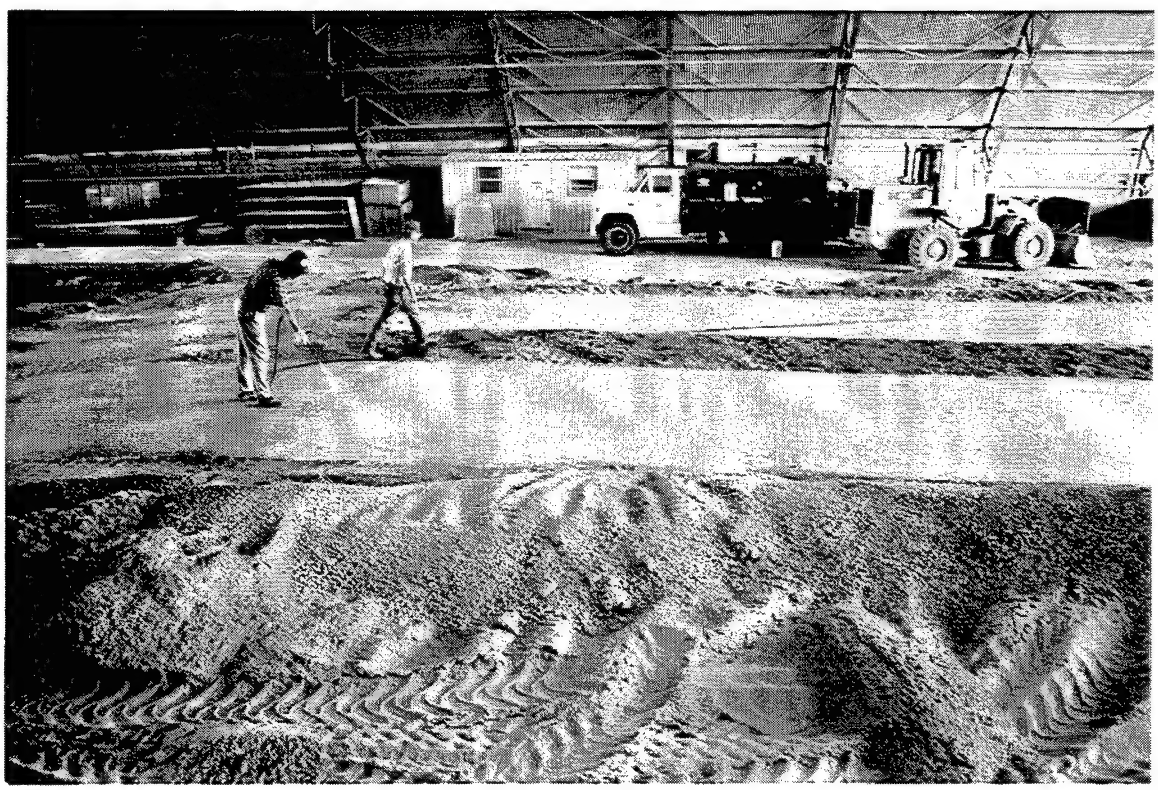

Figure 36. Spraying Road Oyl surfacing

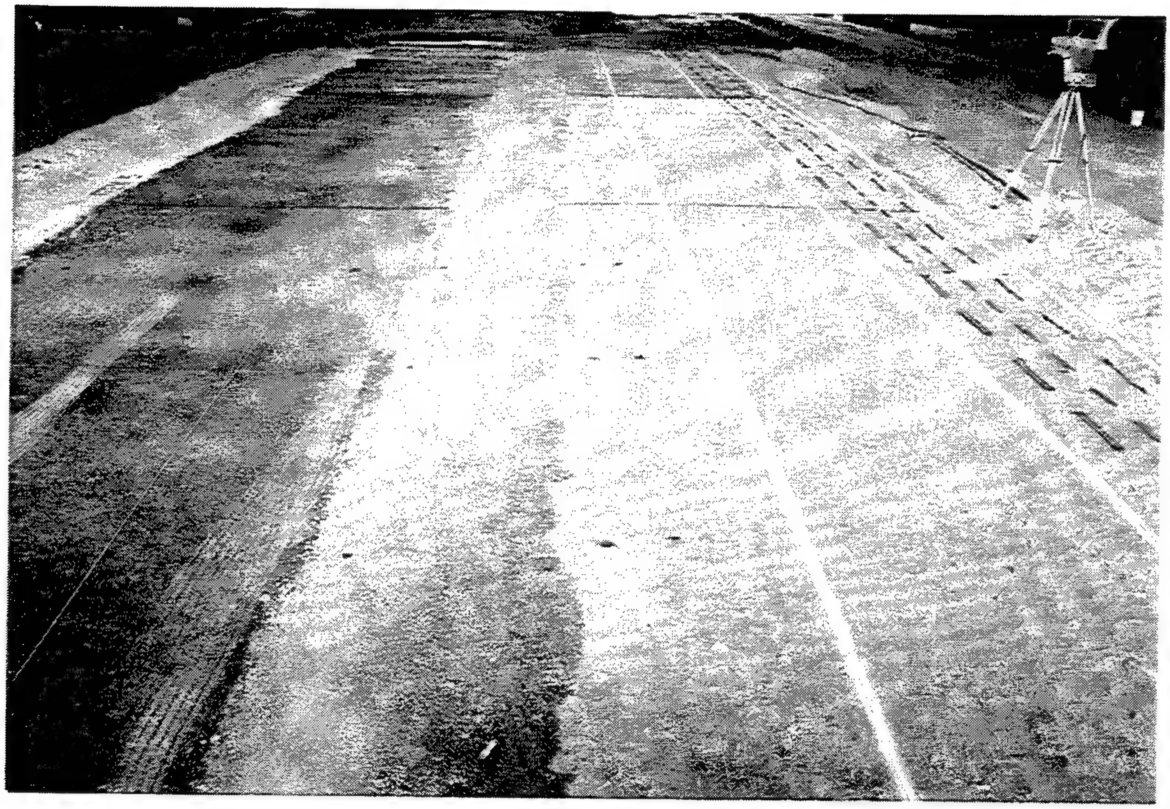

Figure 37. Completed test section

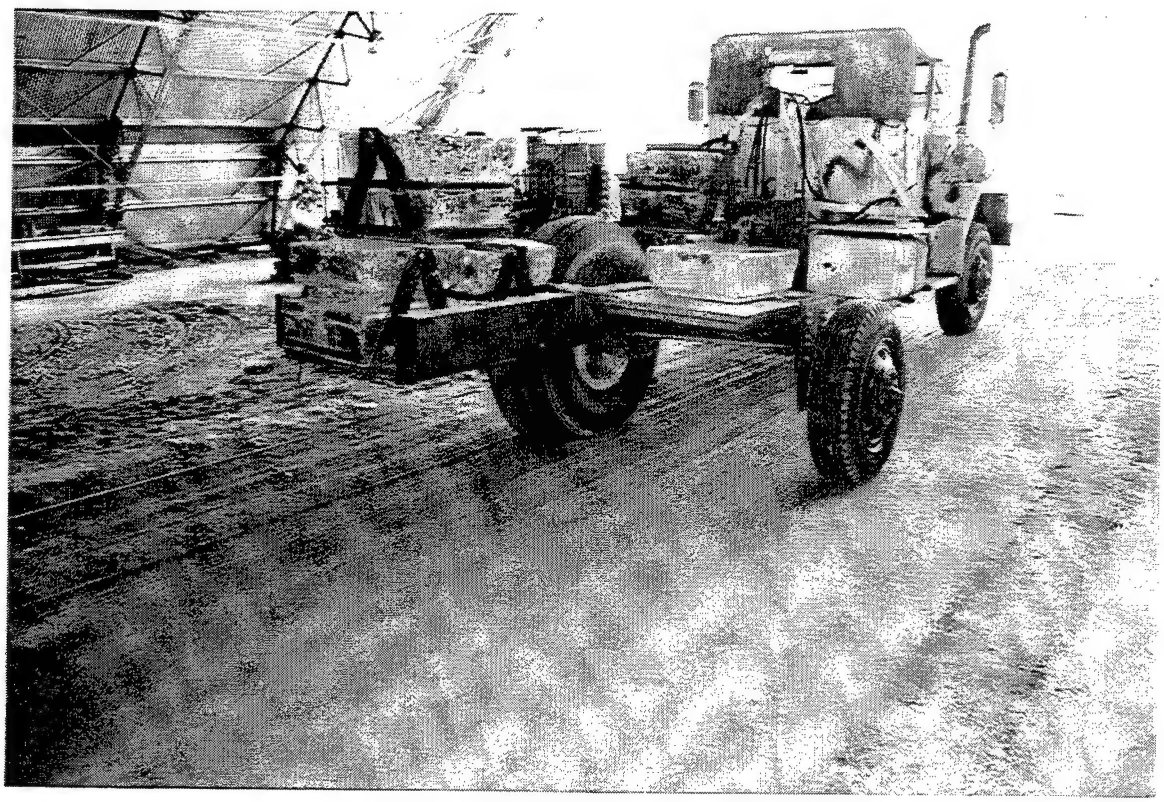

Figure 38. Test cart with 30-kip single-wheel-assembly

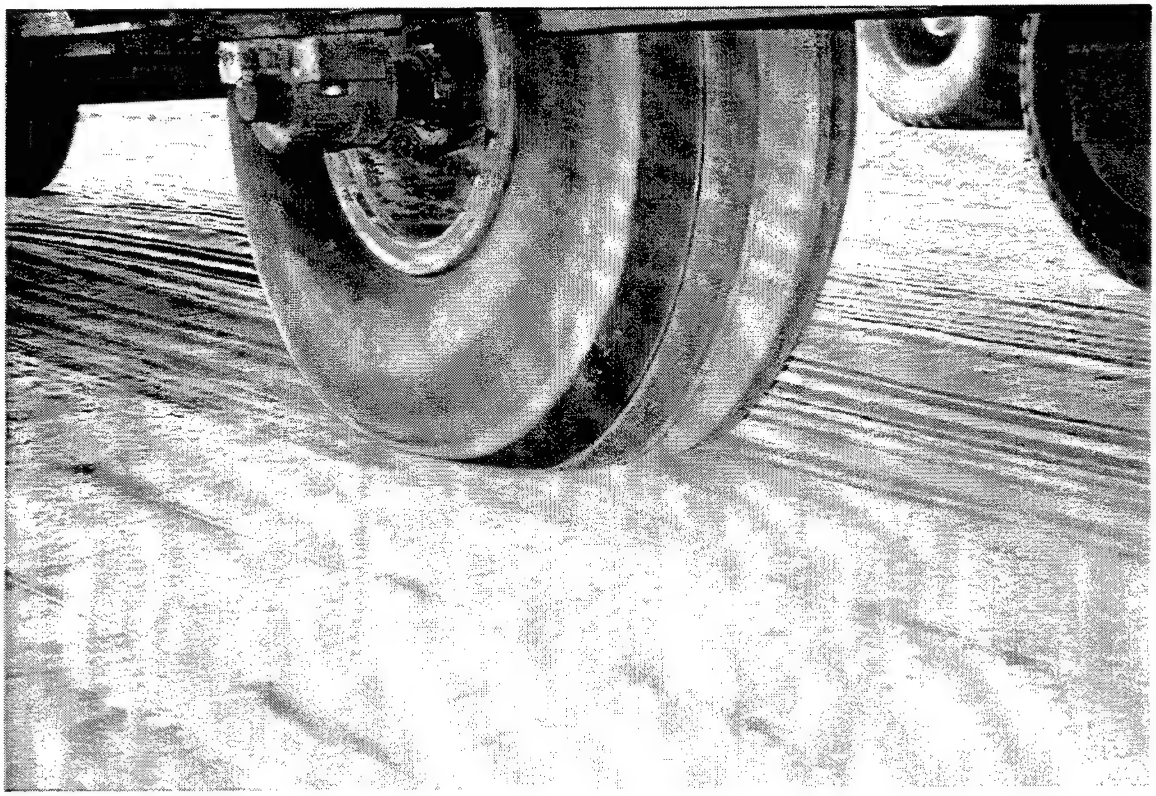

Figure 39. Close-up of loaded tire on item 1

Figure 40. Patching material on small rut between items 2 and 3

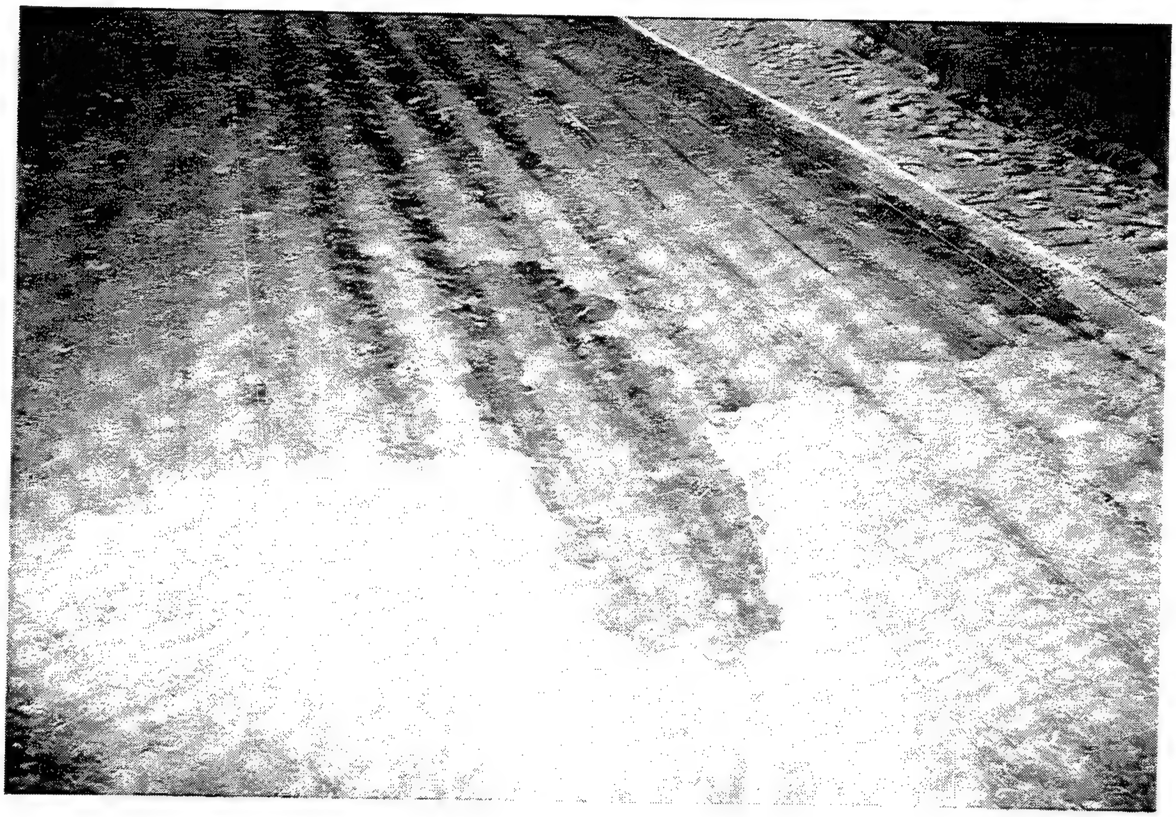

Figure 41. Patched area after traffic compacted the patch

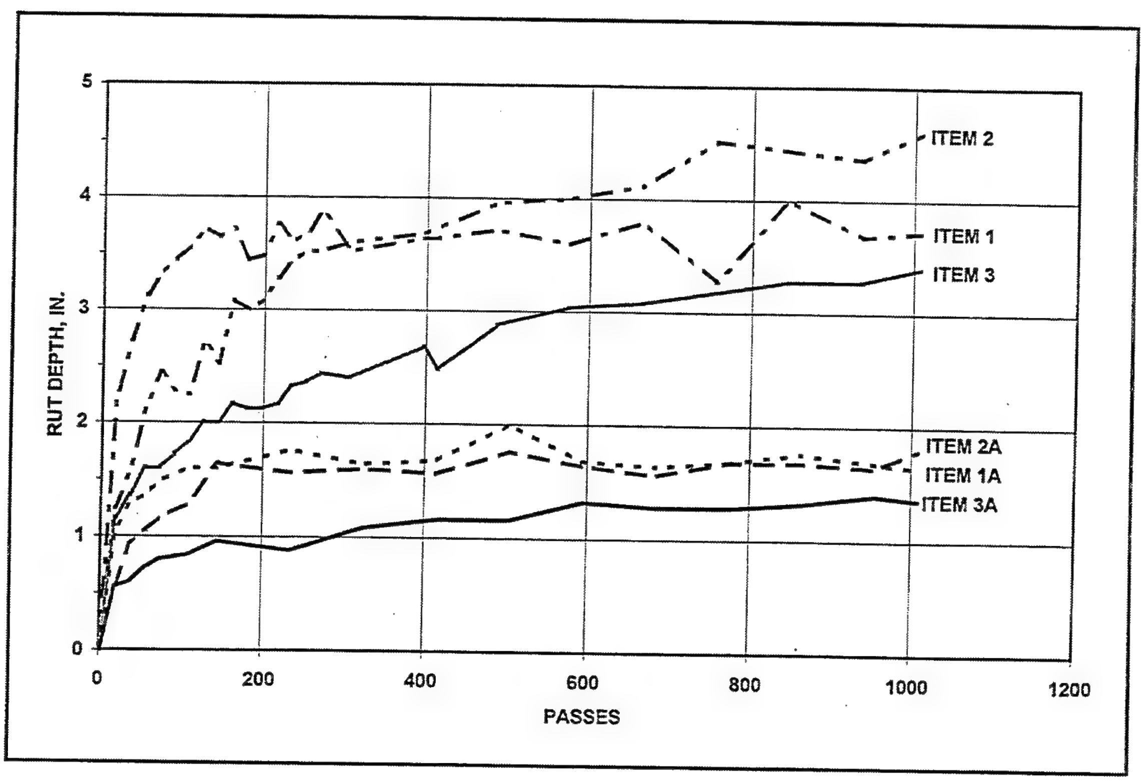

Figure 42. Rutting versus passes, 12-in.-thick items, lanes 1 and 1A

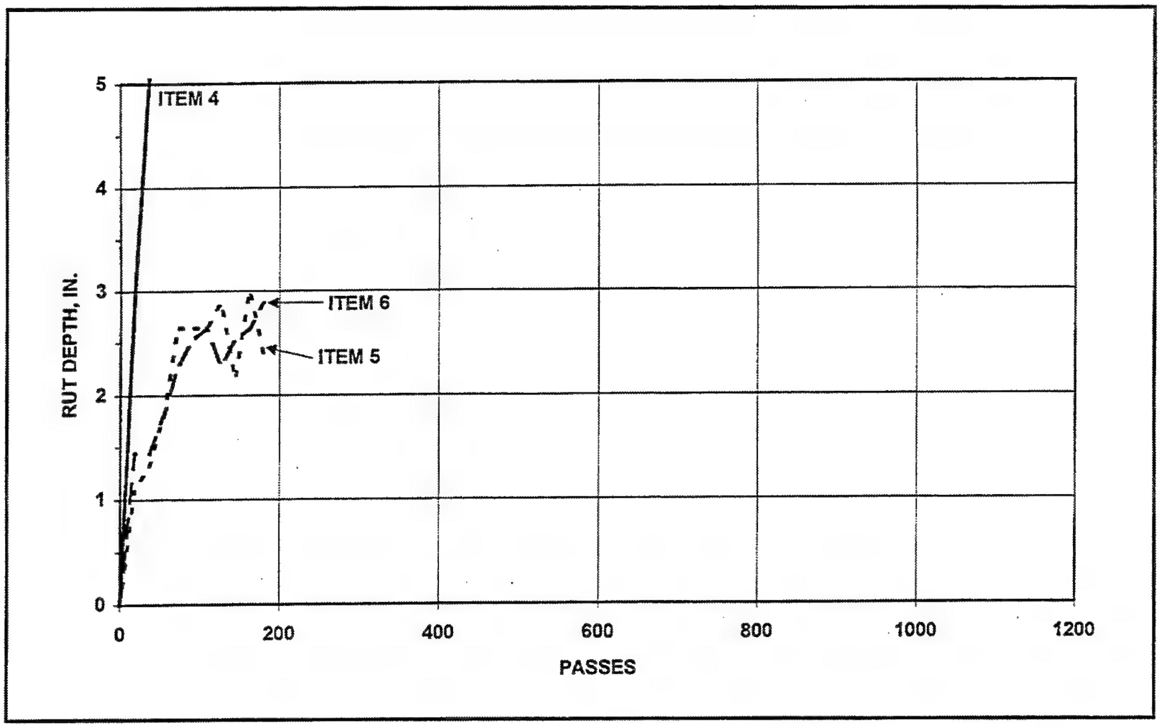

Figure 43. Rutting versus passes, 8-in.-thick items, lane 2

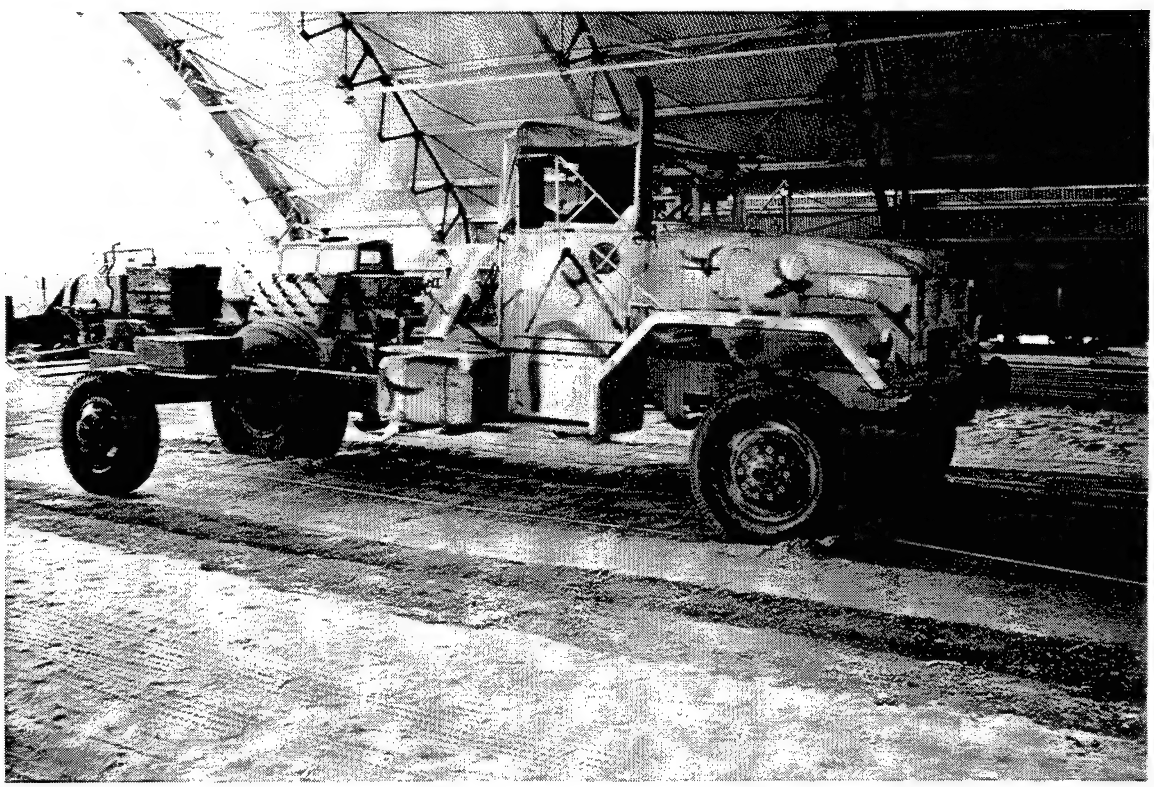

Figure 44. Stuck load cart on item 4 during 25th pass

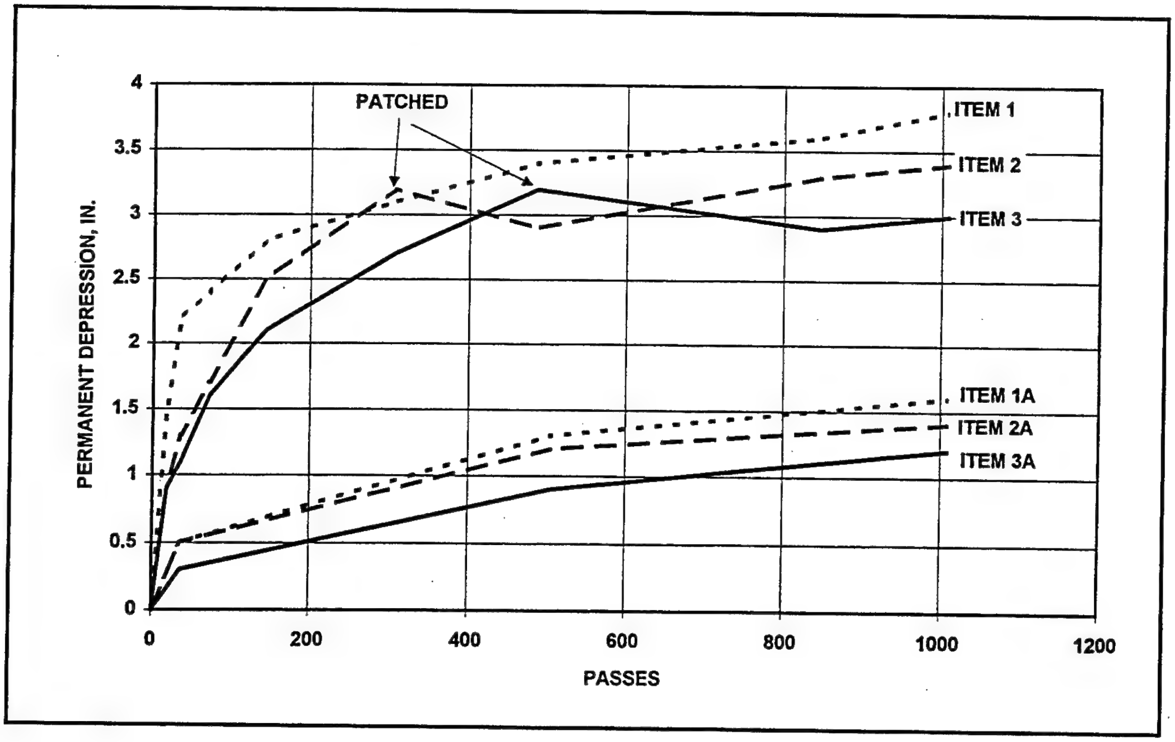

Figure 45. Permanent surface depression, 12-in.-thick items

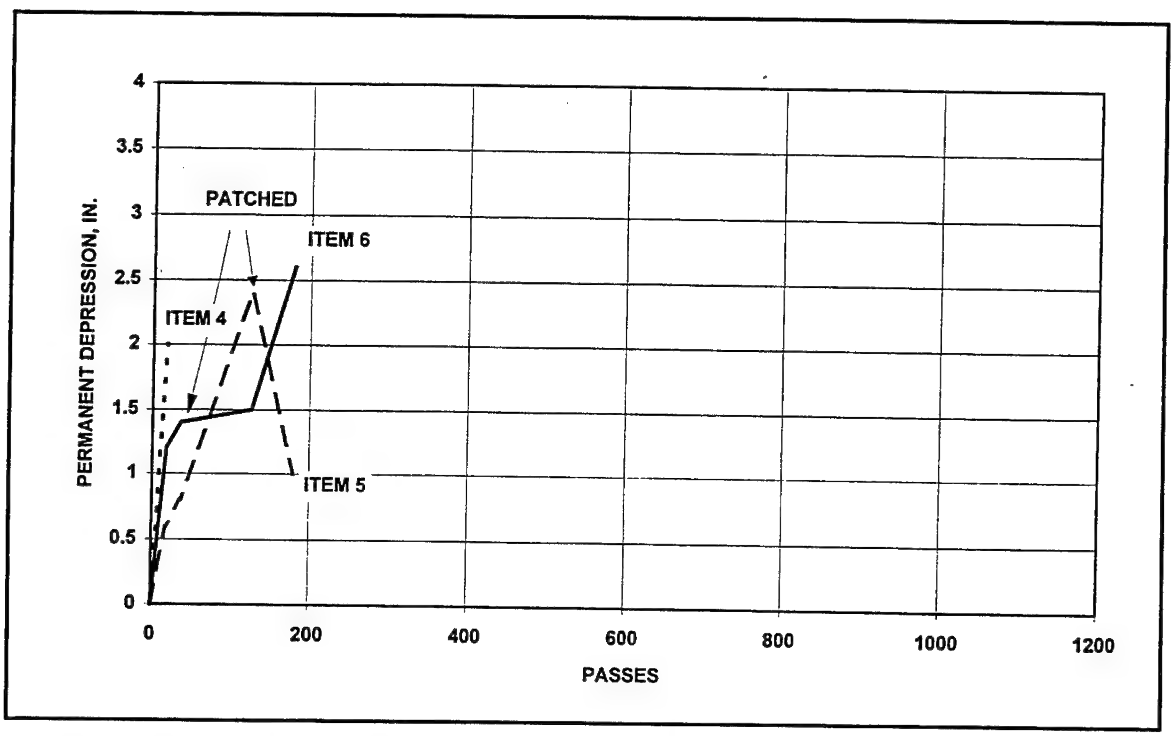

Figure 46. Permanent surface depression, 8-in.-thick items

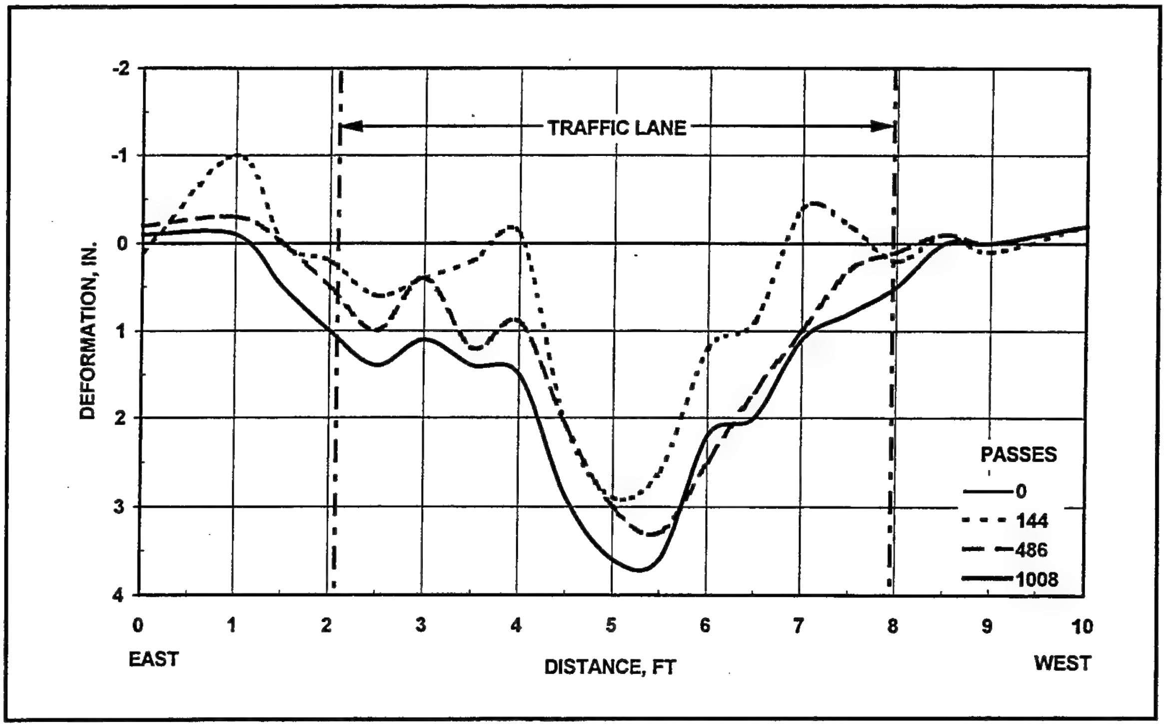

Figure 47. Typical cross sections of permanent deformation, item 1

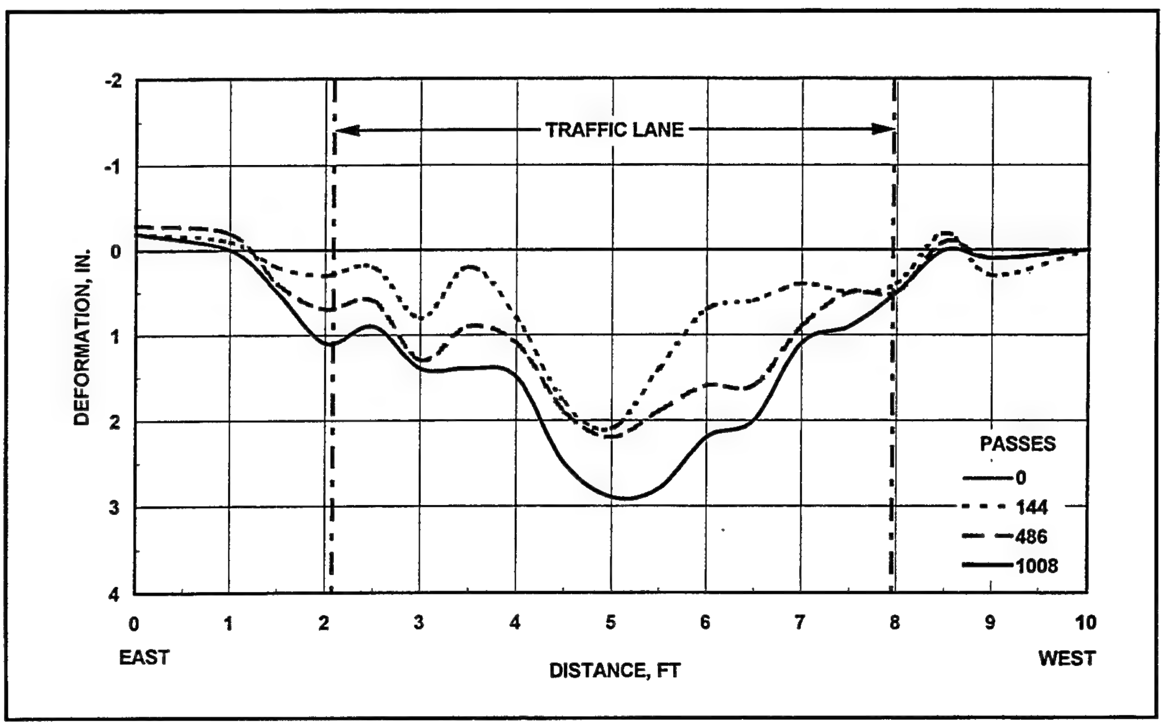

Figure 48. Typical cross sections of permanent deformation, item 2

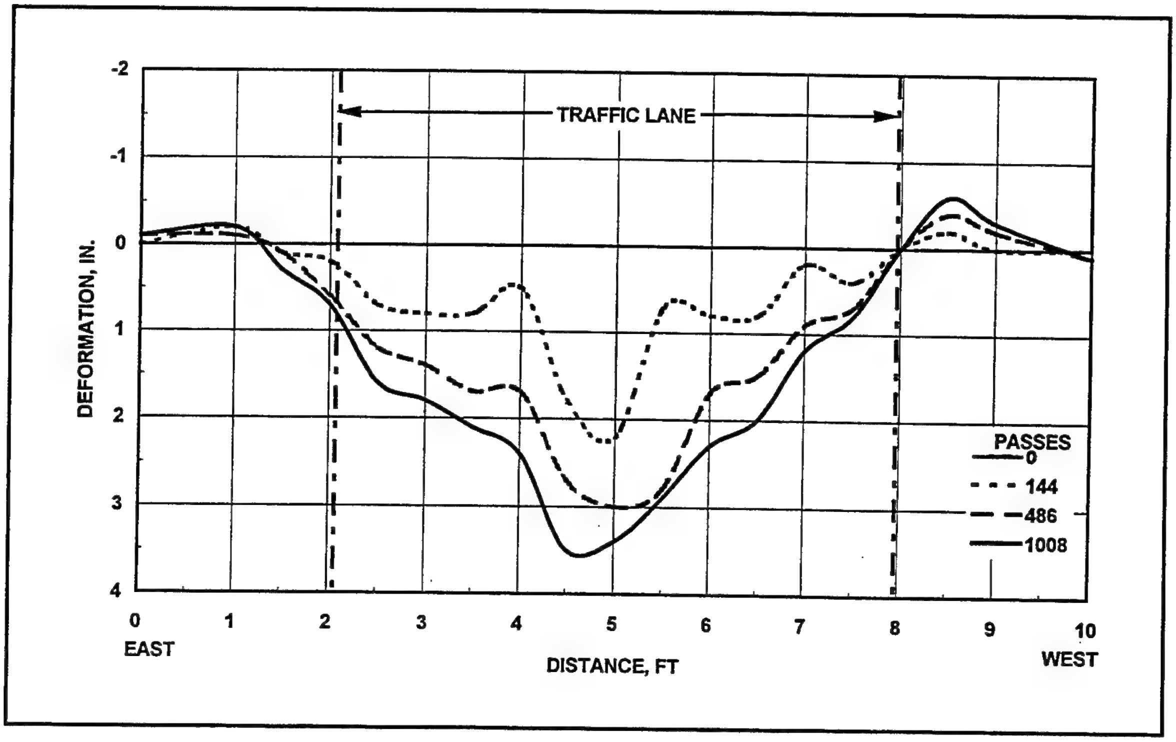

Figure 49. Typical cross sections of permanent deformation, item 3

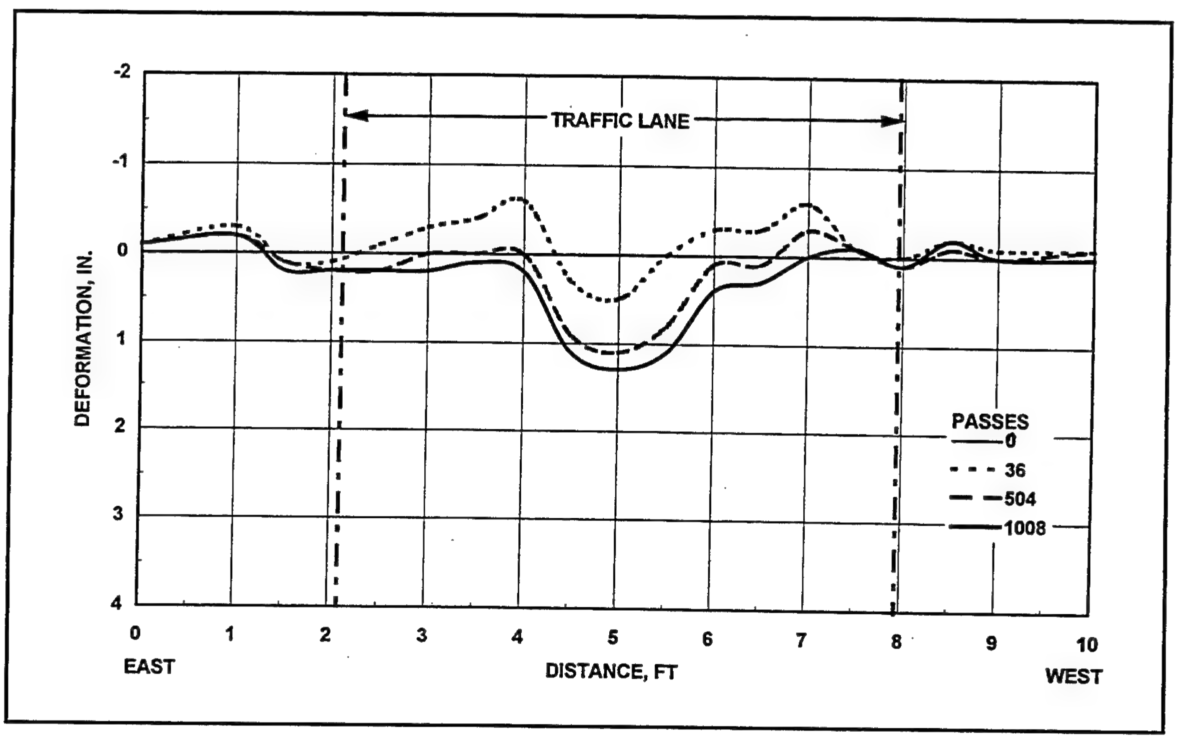

Figure 50. Typical cross sections of permanent deformation, item 1A

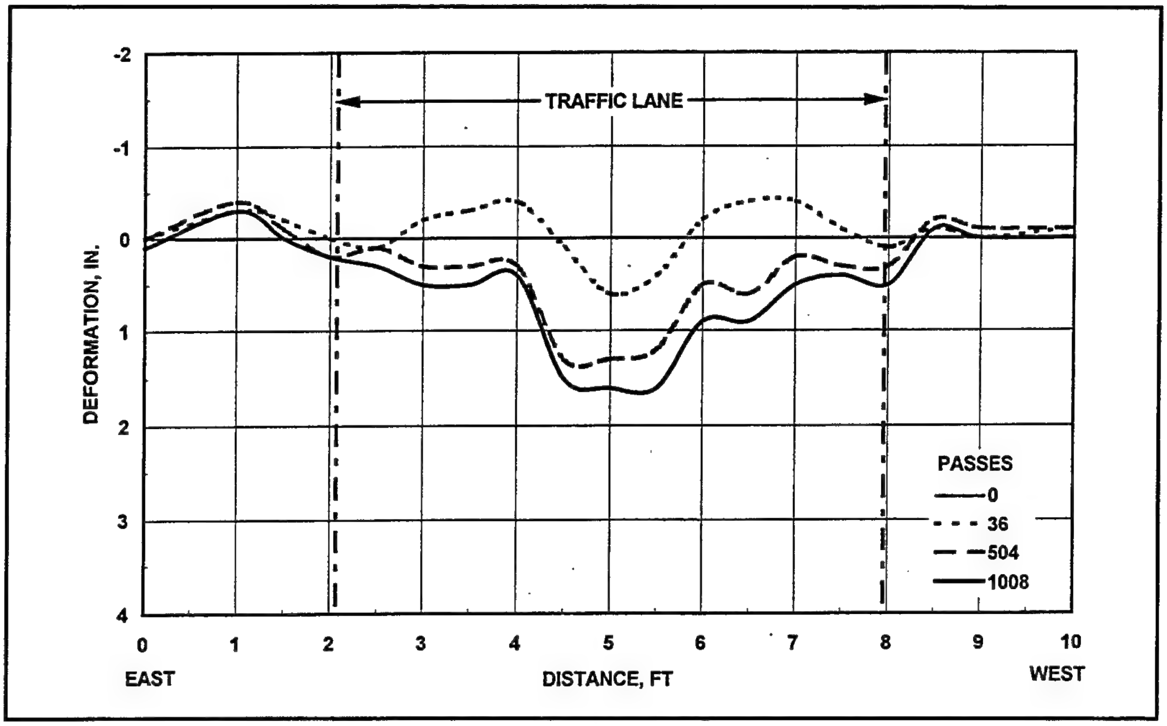

Figure 51. Typical cross sections of permanent deformation, item 2A

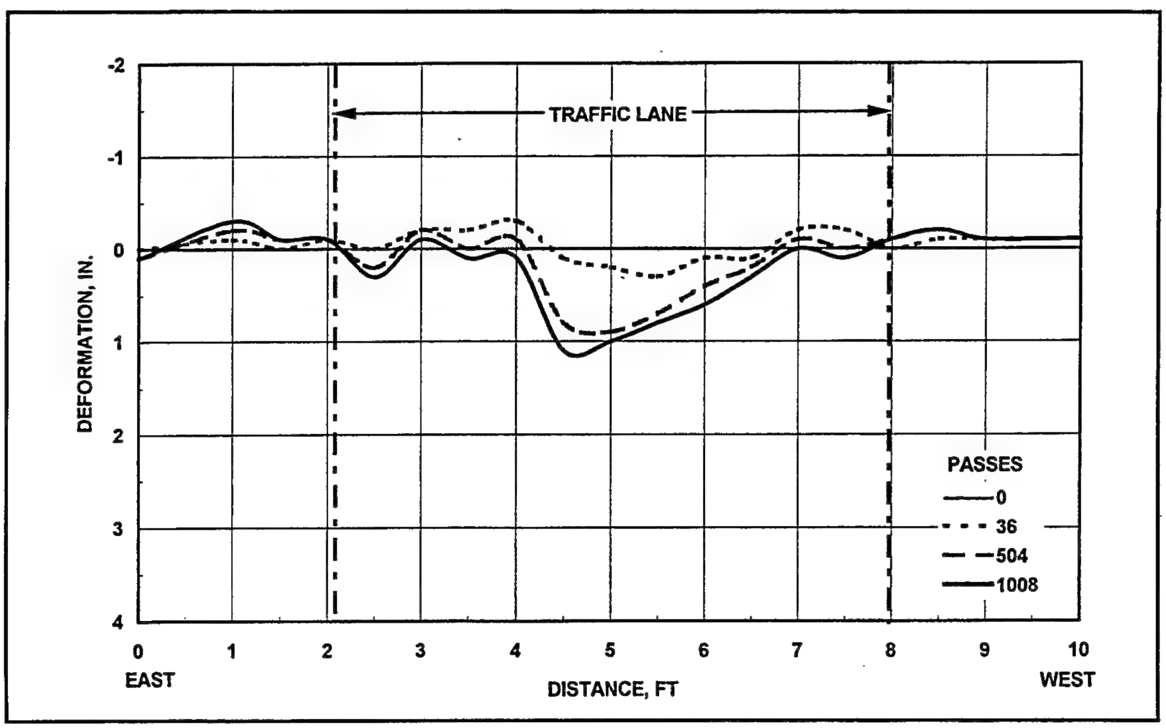

Figure 52. Typical cross sections of permanent deformation, item 3A

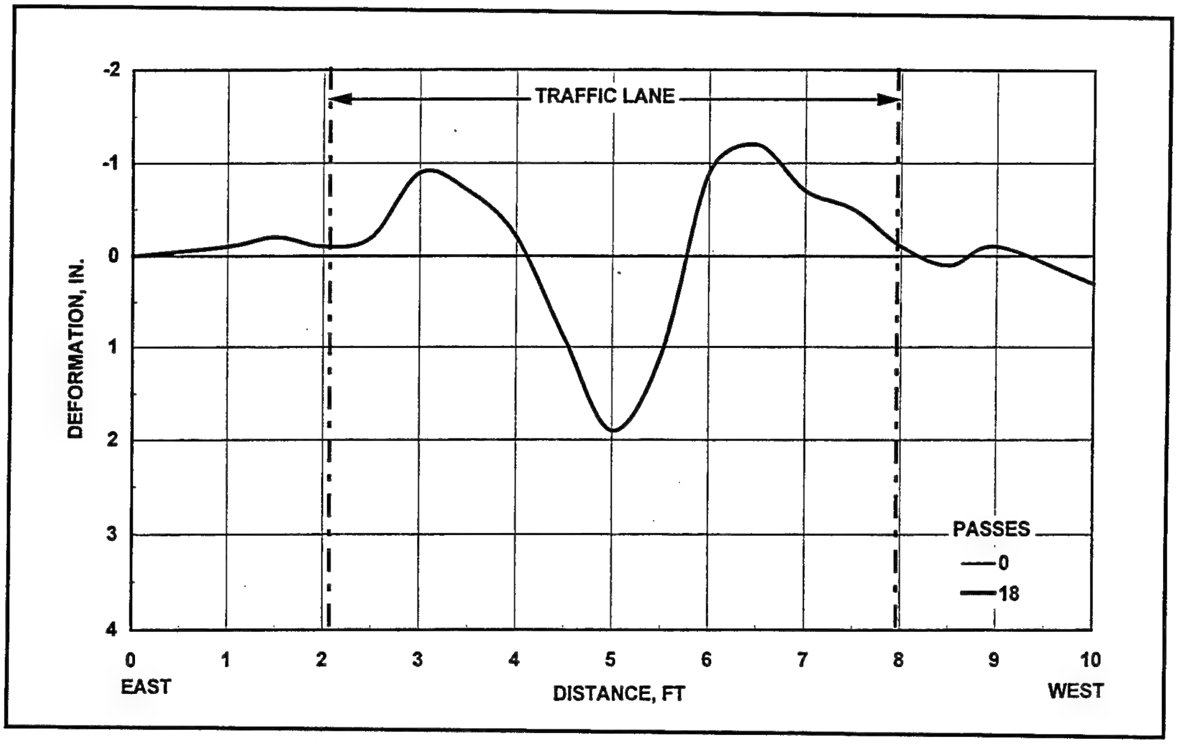

Figure 53. Typical cross sections of permanent deformation, item 4

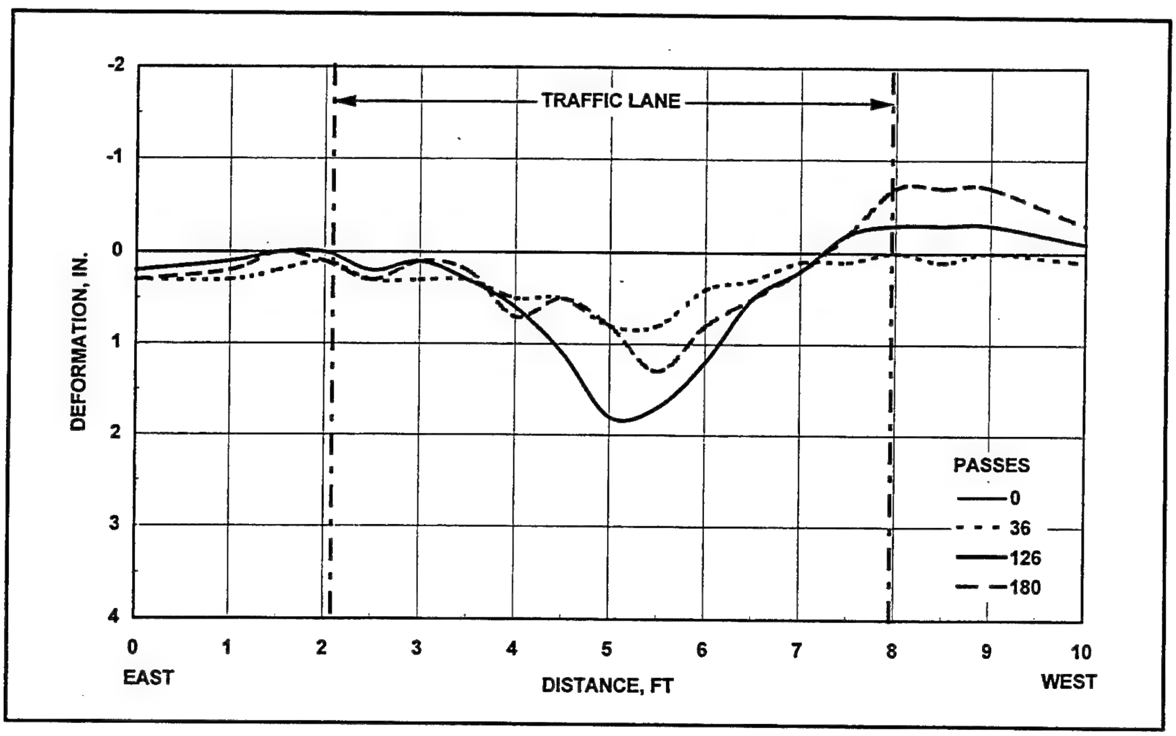

Figure 54. Typical cross sections of permanent deformation, item 5

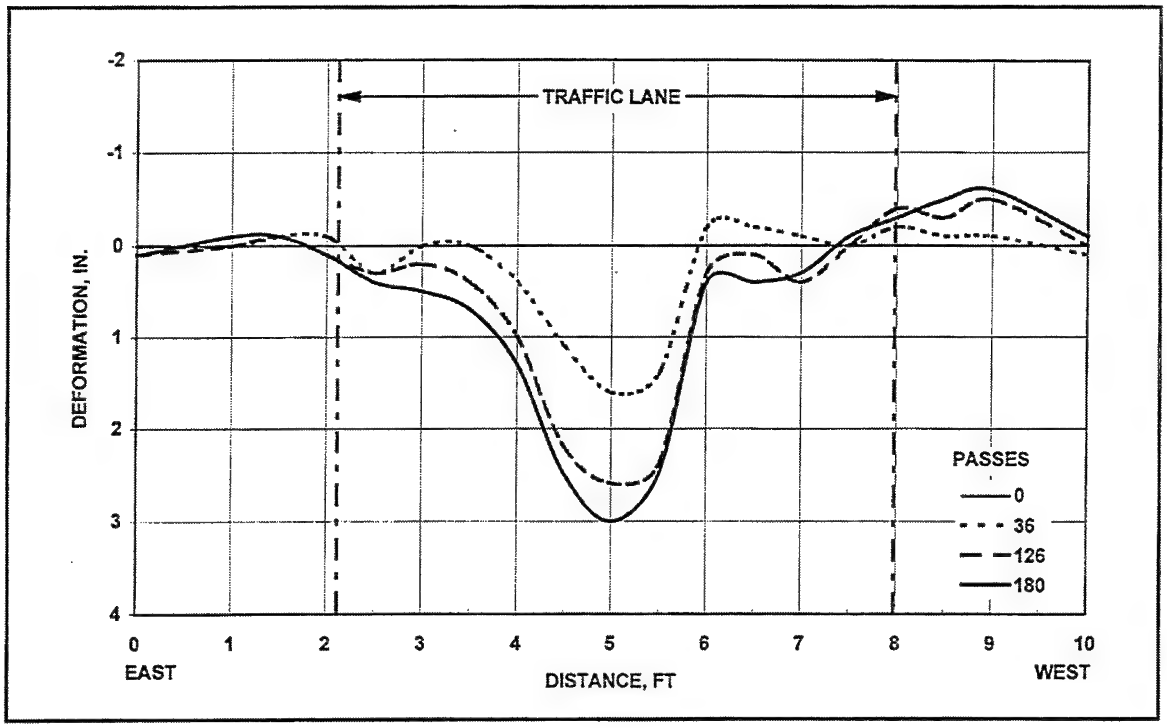

Figure 55. Typical cross sections of permanent deformation, item 6

Figure 56. Item 1 after 1,008 passes

Figure 57. Item 2 after 1,008 passes

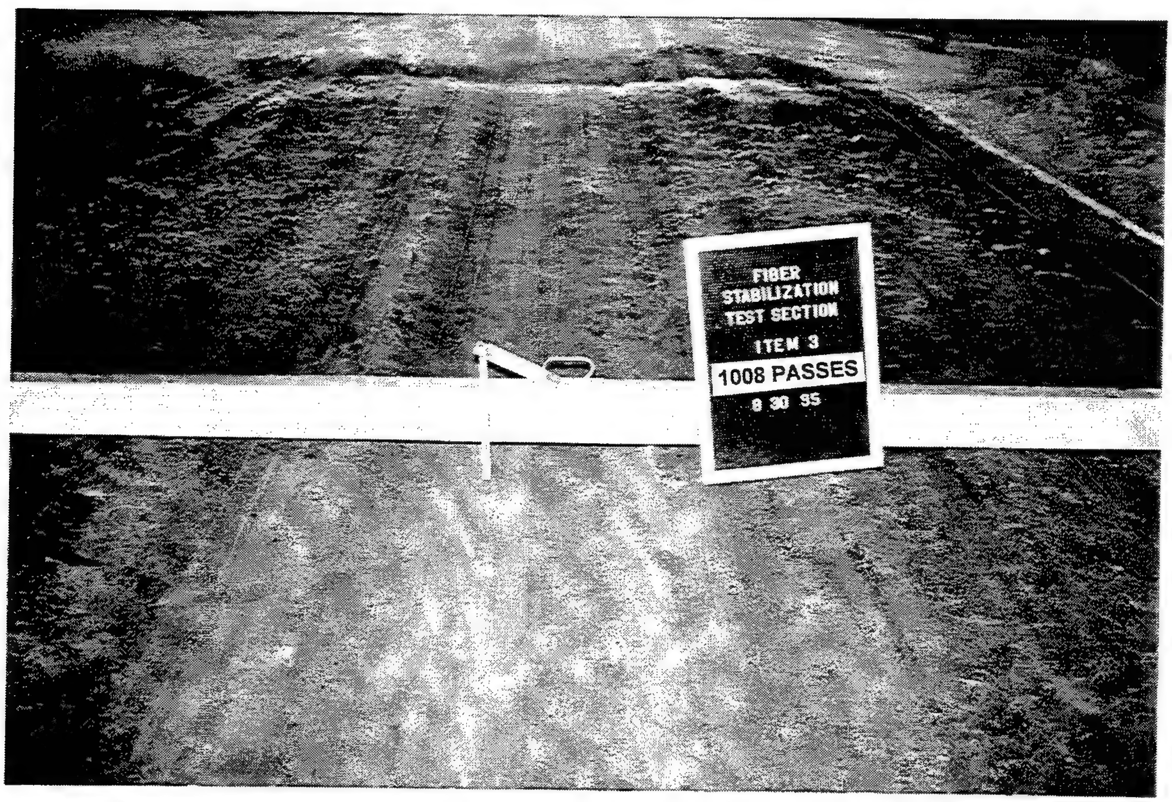

Figure 58. Item 3 after 1,008 passes

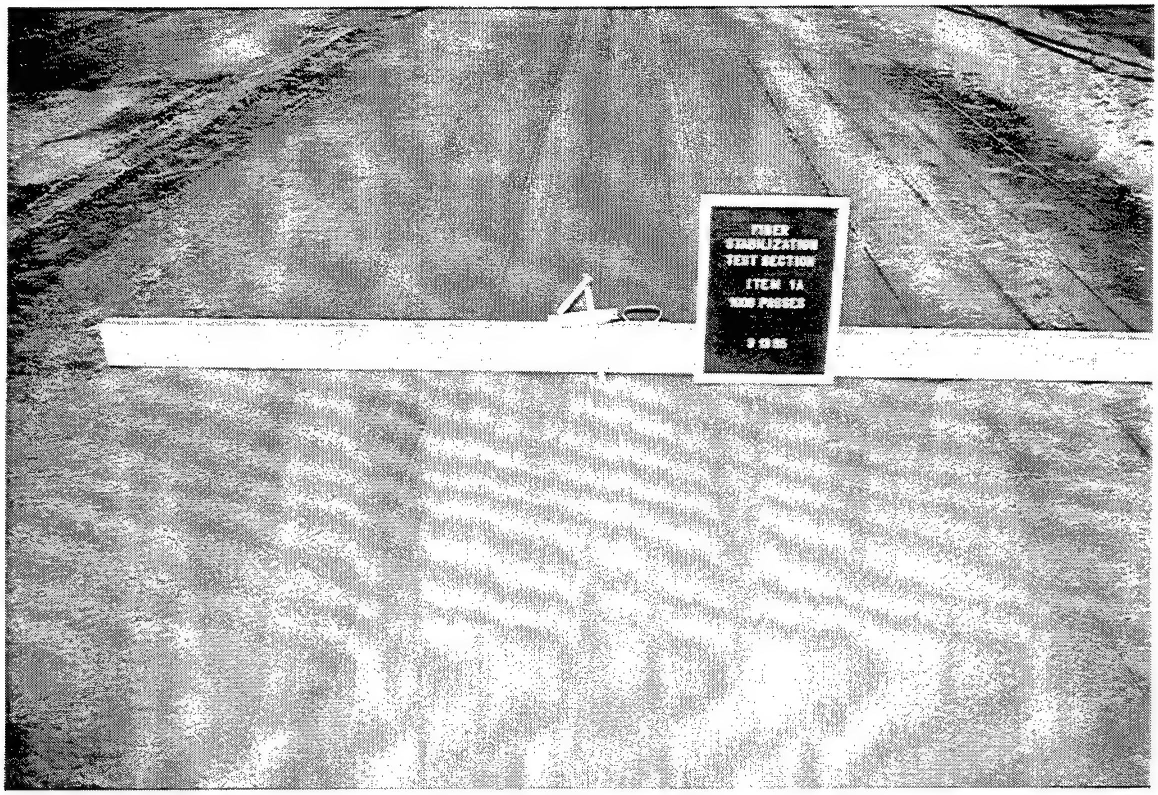

Figure 59. Item 1A after 1,008 passes

Figure 60. Item 2A after 1,008 passes

Figure 61. Item 3A after 1,008 passes

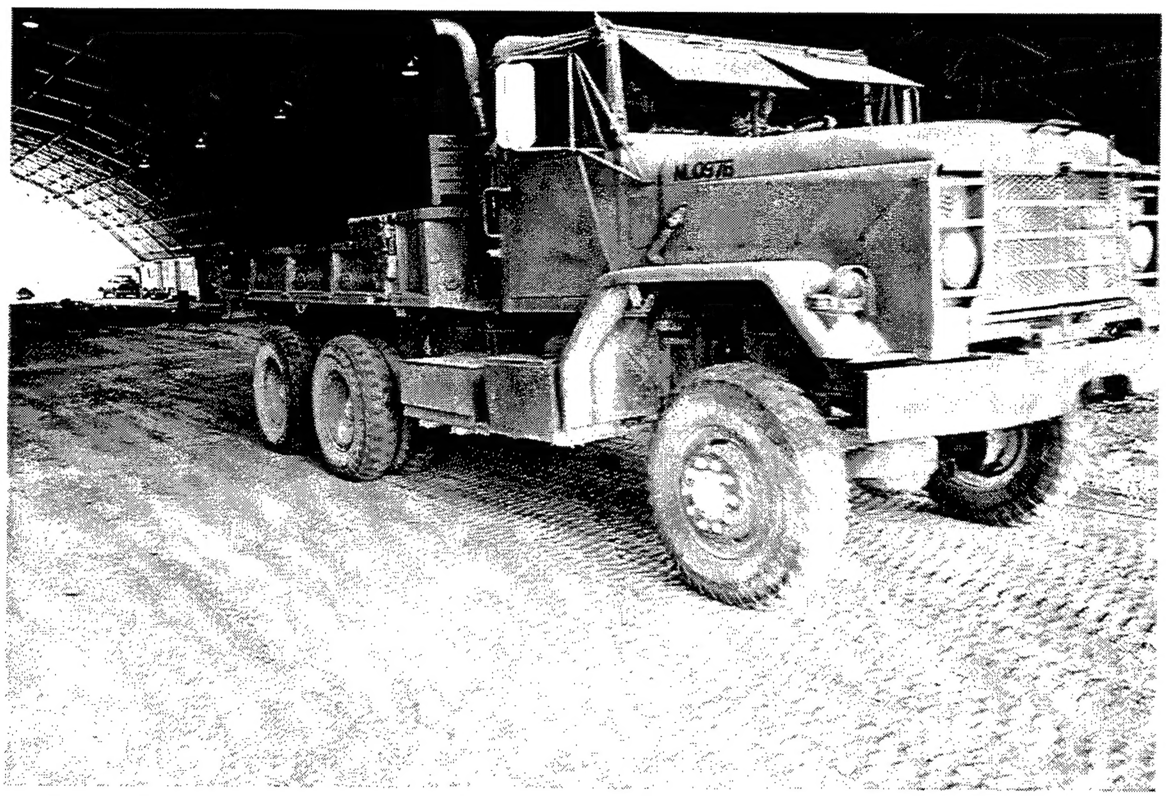

Figure 62. Military truck traffic on test section

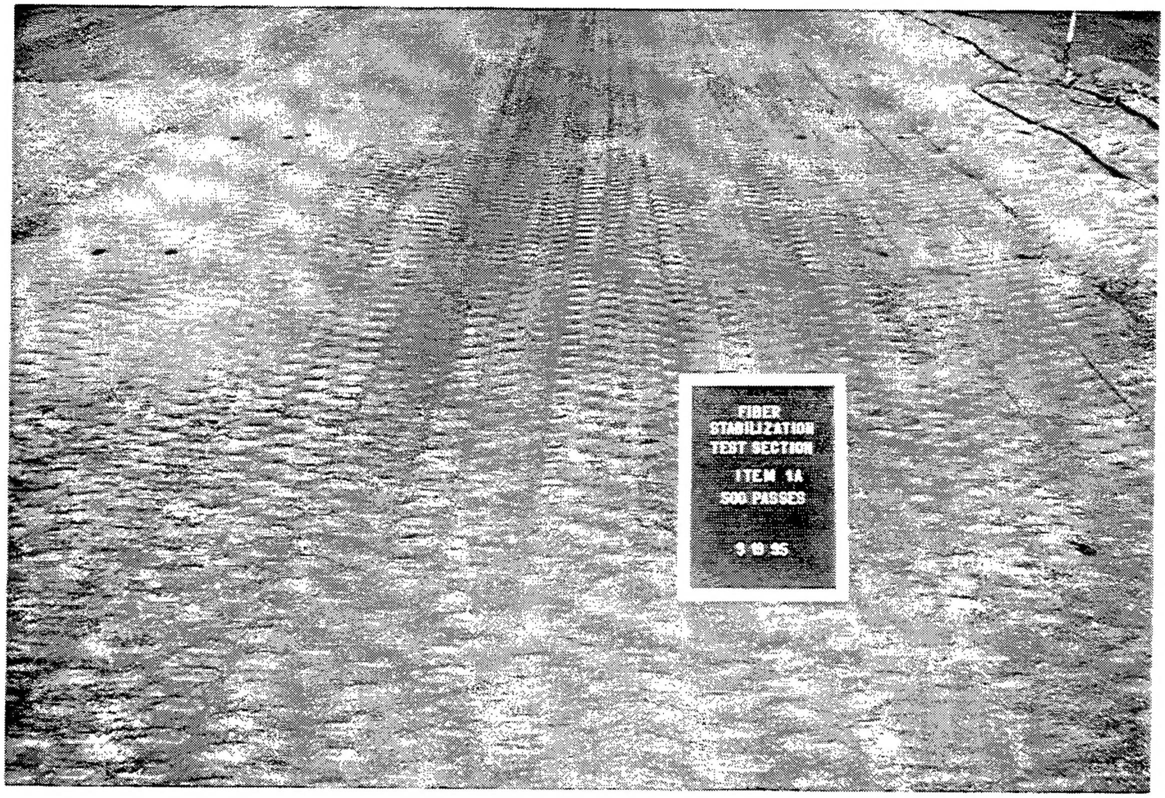

Figure 63. Item 1A after 500 truck passes

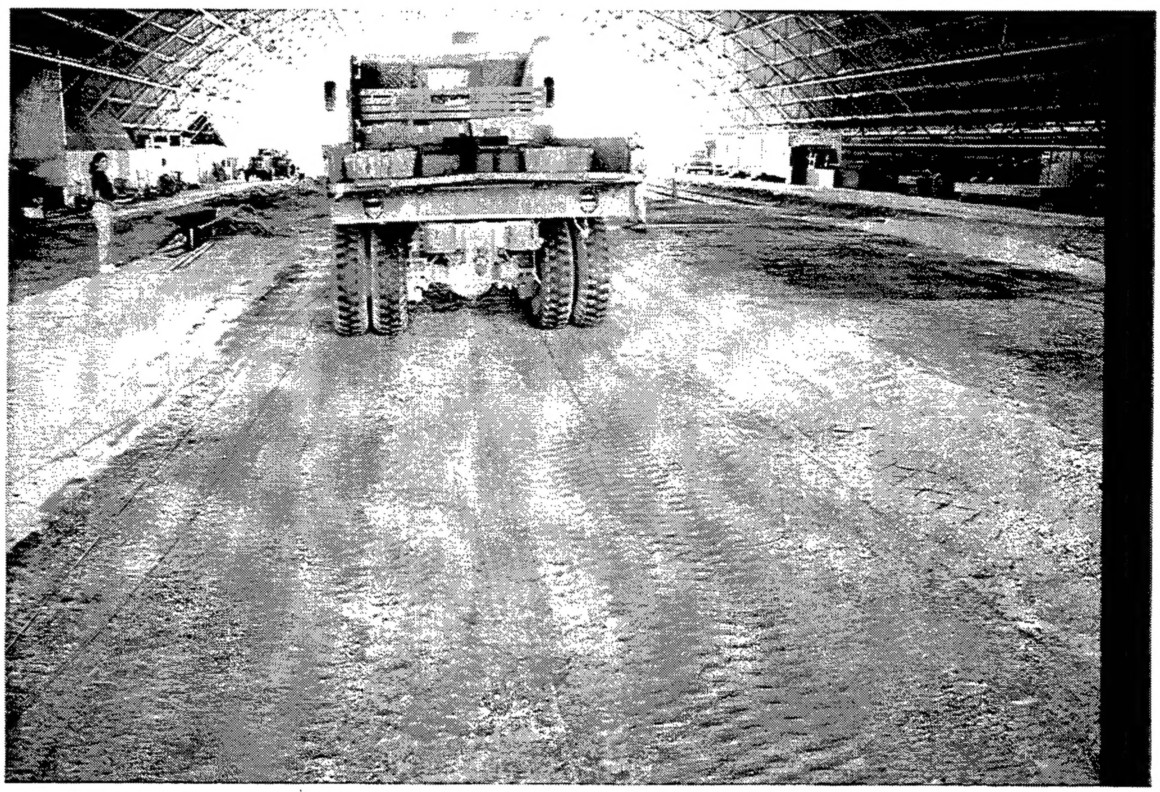
Figure 64. Items 5 and 6 after 120 truck passes

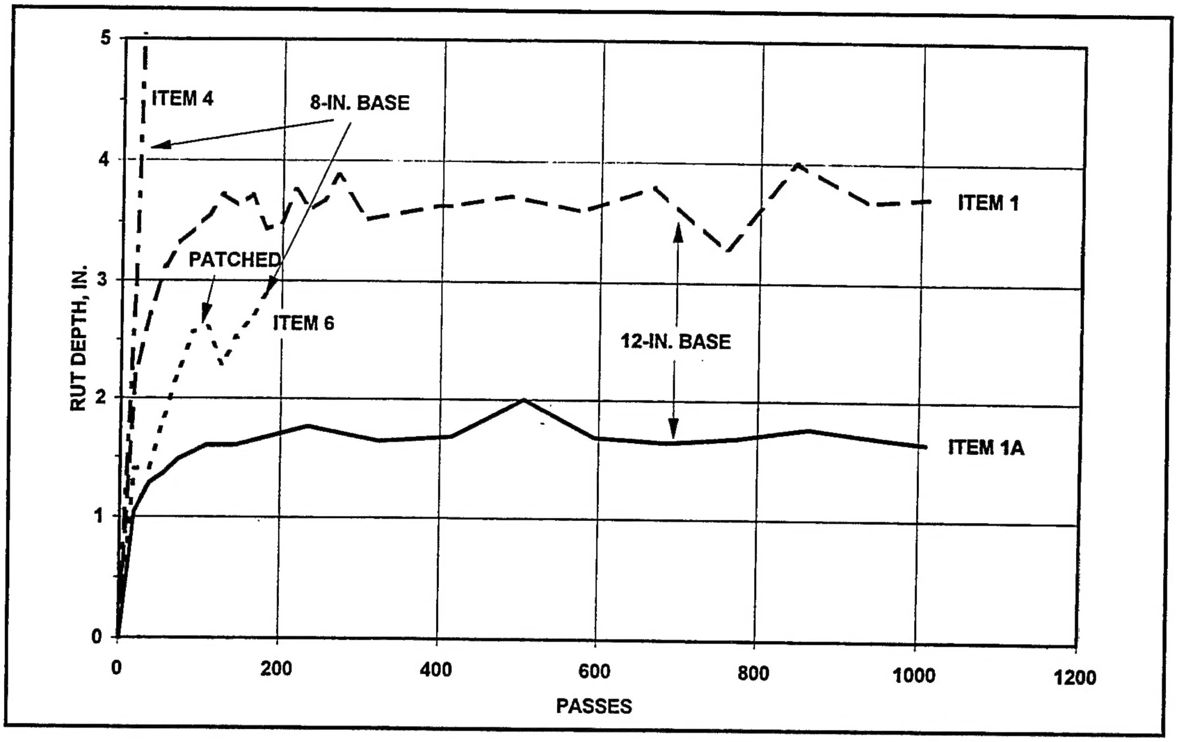

Figure 65. Rutting versus passes for load cart traffic, 8-in.- and 12-in.-thick sand-fiber items

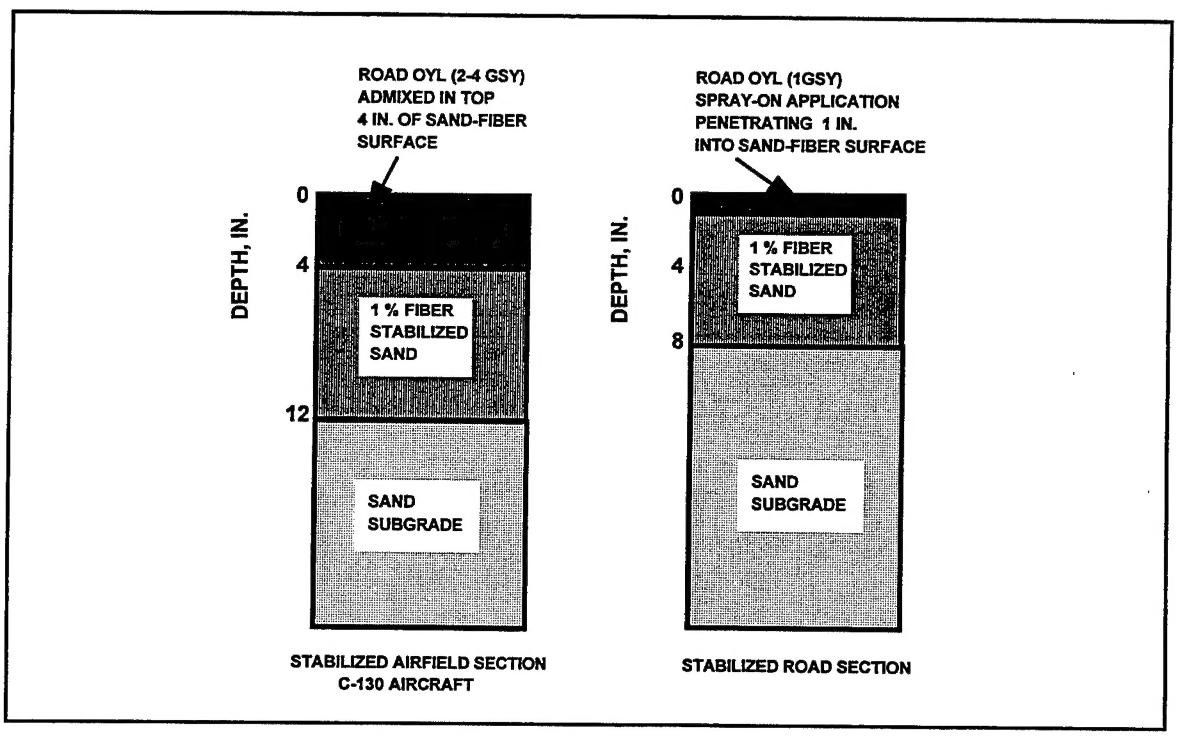

Figure 66. Recommended sand-fiber sections for C-130 aircraft and road applications

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Steve L. Webster, Rosa L. Santoni

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13. ABSTRACT (Maximum 200 words)

This report describes laboratory and field tests conducted using a new fiber stabilization technique for sands. Laboratory unconfined compression tests using 2-in.-long monofilament polypropylene fibers to stabilize a poorly graded (SP) sand showed an optimum fiber content of 1 percent (by weight). Field test sections were constructed and traffic tested using simulated C-130 aircraft traffic (30,000-lb tire load at 100-psi tire pressure) and military truck traffic (5-ton military cargo truck loaded to a gross weight of 41,600 lb).

Test results showed that sand-fiber stabilization over a sand subgrade supported over 1,000 passes of a C-130 tire load with less than 2 in. of rutting. The top 4 in. of the sand-fiber layer was lightly stabilized with Road Oyl to provide a wearing surface. Based on limited truck traffic tests, an 8-in.-thick sand-fiber layer, surfaced with a spray application of Road Oyl, would support substantial amounts of military truck traffic.

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